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Final Technical Report
April 1979

RELIABILITY PREDICTION MODELS FOR MICROWAVE SOLID STATE DEVICES

Martin Marietta Corporation

George F. Guth

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Martin Marietta Corporation conducted a 12 month program to develop base failure rates and failure rate mathematical models for microwave solid state devices. These models are provided in the format of MIL-HDBK-217B. More than 8.75 billion part hours of operating field data were collected from industrial and Government data sources.

Data were analyzed and sorted manually. Conclusions are summarized in the revised base failure rates and mathematical models described. (Cont'd)

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19. (Continued)

Ferrite Phase Shifters, Reliability Models
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GaAs FETs, Reliability Models
Gunn Diodes
Gunn Diodes, Failure Rates
Gunn Diodes, Reliability Models
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Varactor Diodes, Failure Rates
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YIG Filters
YIG Filters, Failure Rates
YIG Filters, Reliability Models

20. (Continued)

Failure rates developed for those devices already included in MIL-HDBK-217B are compared with present failure rates. Devices not presently included in MIL-HDBK-217B are listed with new pages for inclusion in MIL-HDBK-217B.

EVALUATION

This report describes a study of reliability prediction models for microwave solid state devices. Due to limitations in data, it was necessary, in some cases, to use engineering judgement to supplement available data to provide the models. This study was performed under TPO R5B, "Solid State Device Reliability." The results of the study will be compared to data from other sources, such as the PAVE PAWS radar, and then sent to industry and DOD agencies for comments for inclusion in MIL-HDBK-217, "Reliability Prediction of Electronic Equipment."

John F Carroll
JOHN F. CARROLL
Project Engineer

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ILLUSTRATIONS

PREFACE

This final report was prepared by the Product Engineering Laboratory of Martin Marietta Corporation, Orlando, Florida, for the Rome Air Development Center (RADC), Griffiss Air Force Base, New York, under Contract F 30602-77-C-0204.

Major objectives of this study were to develop base failure rates and failure rate mathematical models for microwave solid state devices. The microwave solid state devices studied were GUNN devices, Schottky Diodes, IMPATT diodes, PIN diodes, GaAs Field Effect Transistors, Circulators, Capacitors, Low Noise Transistors, Ferrite Phase Shifters, Loads and Terminations, SAW devices, Varactor diodes, and YIG filters.

The contract was issued in September, 1977, by Rome Air Development Center. Mr. John Carroll (RBRP) was the RADC Project Engineer. The period of contract performance was from September, 1977 to September, 1978.

Technical assistance in acquisition of the data was provided by Messrs. Thomas Butler, Bradley Orr, and William King. In addition, other Martin Marietta study team members were Messrs. Donald Cottrell, Jeff Bracey, and Mmes. Betty Jean Thomas and Tina Chin. Technical consultation was provided by Mr. Neil Owen and Dr. Deen Khandelwal.

LIST OF ABBREVIATIONS

CW	Continuous Wave
dc	Direct Current
DDC	Defense Documentation Center
ECM	Electronic Countermeasures
FET	Field Effect Transistor
FM	Frequency Modulation
GaAs	Gallium Arsenide
Ge	Germanium
GHz	Gigahertz
HDBK	Handbook
Hz	Hertz
IDT	Interdigital Transducer
IF	Intermediate Frequency
IMPATT	Impact Ionization Avalanche Transit Time
InP	Indium Phosphide
kHz	Kilohertz
$LiNBO_3$	Lithium Niobate
LSA	Limited Space Charge Accumulation
λ	Lamda (Failure Rate)
LIDS	Leadless Inverted Device
MIC	Microwave Integrated Circuit
MIL	Military
NTIS	National Technical Information Service
PIV	Peak Inverse Voltage
PRF	Pulse Repetition Frequency
RADC	Rome Air Development Center
RF	Radio Frequency
SAW	Surface Acoustic Wave
SiO_2	Silicon Dioxide
SOS	Silicon on Sapphire
SIDD	Silicon Double Drift
TED	Transferred Electron Device
TIC	Technical Information Center
Tss	Tangential Signal Sensitivity
TWT	Traveling Wave Tube
VTO	Varactor Tuned Oscillator
VSWR	Voltage Standing Wave Ratio
YIG	Yttrium Iron Garnet

SUMMARY

Reliability information and data on microwave solid state devices were studied from September, 1977, to September, 1978. Major objectives of this study were to develop base failure rates and failure rate mathematical models for 13 categories of microwave devices to be included in MIL-HDBK-217B. The models can be used in conjunction with base failure rates by applying appropriate environmental, circuit use, application, and packaging factors in order to estimate device failure rates.

The study was initiated by mailing a survey questionnaire to sources within industry and Government agencies. This was followed by telephone contact with survey respondents and personal visits to those respondents indicating having the most favorable data response. Sumultaneously, library research data were reviewed. All data collected were sorted and analyzed manually.

Collected data on microwave solid state devices were grouped, analyzed, and tested for homogenity before combination. A 60 percent confidence limit was calculated for all data under evaluation. A complete device type listing was developed for data used to generate operating failure rates for MIL-HDBK-217B.

More than 8.75 billion part hours of operating data were collected in this study. The data covers PIN diodes, Schottky diodes, Varactor diodes, dummy loads and terminations, microwave capacitors, circulators, isolators, ferrite phase shifters and low noise transistors in ground fixed, ground mobile, naval sheltered, and space flight environments. Data from laboratory life tests and evaluations were collected on GaAs FETs, IMPATT diodes, Gunn diodes, SAW devices, and YIG filters. Expert engineering judgment was utilized to develop reliability mathematical models in areas where data were insufficient to provide determination of failure rates solely by mathematical calculation.

1.0 INTRODUCTION

MIL-HDBK-217B, "Reliability Prediction of Electronic Equipment", is the current source of reliability prediction models for estimating reliability of proposed equipment designs. Models in the handbook used to predict failure rates for microwave solid state devices have fallen behind current trends and technology.

The purpose of the contract was to revise or develop models for predicting failure rates for microwave solid state devices. These models have been constructed and validated. They facilitate reliability assessment based on the device type, complexity, application, stresses, operational environment, and other significant influence factors. Results of the contractual effort include a complete listing of data by component type, methodology for data analysis and modeling, and assumptions as procedures followed for constructing reliability prediction models and failure rate data for incorporation into MIL-HDBK-217B.

2.0 DATA COLLECTION

Literature Review

Data for operating failure rates of microwave solid state devices have been collected from contractors, institutions, and systems manufacturers. A comprehensive literature review was made to obtain information and pertinent data on these components. Martin Marietta's Technical Information Center (TIC) was researched for up-to-date information. A bibliography, constructed using key words, was formulated and reviewed for applicability. Data sources used in this computer search included Martin Marietta in-house documents and documents listed by other documentation centers, such as the Defense Documentation Center (DDC), NASA Scientific and Aerospace Reports (STAR), and National Technical Information Service (NTIS).

Data Source Contacts

Upon contract initiation, a list of potential data sources was generated, using previous study contracts and Government-Industry Data Exchange Program (GIDEP) memberships for guidelines. Other sources resulted from consultation with RADC. A total of 328 companies and agencies were on the mailing list for the data survey letters, with answers being gathered from 56 companies. Each survey sheet returned was reviewed carefully to determine whether the data available would be useful in this study. Each respondent to the survey was contacted by telephone to further detail the amount and type of reliability information available. In areas where significant data retrieval was possible, visits by Martin Marietta personnel were arranged. During these visits, operational data were reviewed, reduced, and returned to Martin Marietta for further analysis. A total of 16 data sources were visited, with trips completed to the Northeast, the Washington D.C. area, Los Angeles, San Francisco, and the Southeast.

A summary of data sources contributing to this study is listed in Appendix A.

3.0 FAILURE MODE MECHANISM DATA AND RELIABILITY DESIGN NOTES

Failure mode and mechanism data and design note information were obtained from telephone conversations and visits to major component manufacturers and a cross-section of component users. The objective of this comprehensive industry survey was to identify problem areas. Failure mode information was collected for the various categories of microwave solid state devices included in this report.

3.1 Gunn Devices

The Gunn effect, first observed around 1963, is a mechanism by which dc power can be converted directly to microwave frequencies. The Gunn effect device is sometimes known as a Bulk Effect Device or Transferred-Electron Effects Device (TED).

The basic oscillation of a Gunn effect device is caused by the negative resistivity of N type GaAs or InP, the semiconductor material. When a sufficient dc voltage is applied across the semiconductor material, microwave oscillations occur in the current flowing through the material. These oscillations are found to have a time period related to the transit time of the carriers from the cathode to the anode.

Gunn effect devices are predominately produced from N+ GaAs material. A highly conductive substrate slice of GaAs is lapped and polished. A layer of highly doped GaAs is grown onto the N layer. This prepares the slice for processing into a Gunn effect device.

Gunn device are used as low power (< 40 MW CW) or as medium and high power devices (40 MW to 1W). For processing into low power devices, the substrate material is lapped to the required thickness. Metal contacts are evaporated on the epitaxial N+ layer. The unwanted areas of GaAs are etched away and the result is a mesa of GaAs with a contact in the center. (See Figure 1). The connection to the device is usually formed by a 25 micron gold wire thermo-compression bonded onto the metal contacts. For medium to high power applications the device manufacturing techniques are essentially the same, except the device area is considerably larger. A greater amount of power is dissipated in these devices, and the device is inverted (Epi-down) so the active layer can be close to the heat sink. (See Figure 2).

Gunn devices are used in a variety of applications. Fixed frequency Gunn oscillators have been produced which are used as intrusion alarm type devices, traffic signal activators, automobile type radars, for antiskid

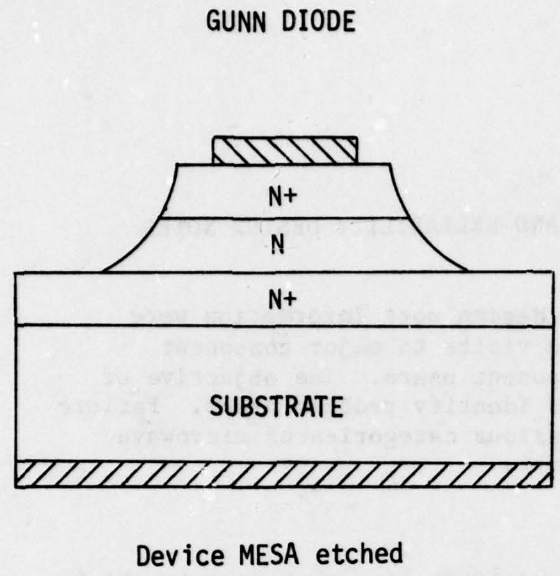


Figure 1. Low Power Gunn Diode (Epi-Up)

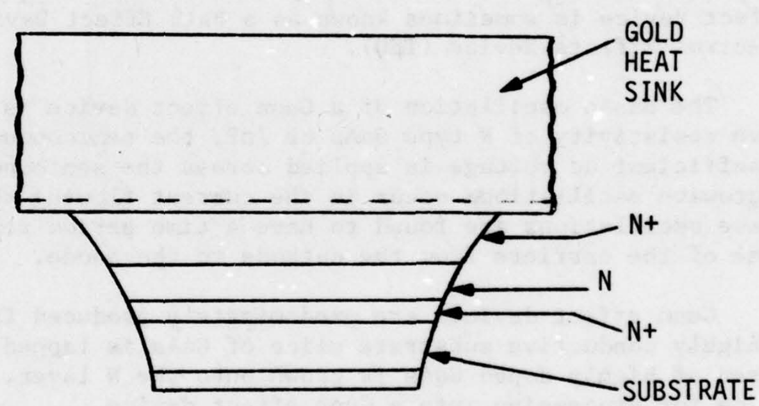


Figure 2. High Power Gunn Diode (Epi-Down)

systems, radar speed meters, and rotational speed transducers. Other applications in tuneable oscillators are local oscillators in pulsed radar system and sources for FM cw radars.

The reliability of the Gunn device, because it is used as a solid state microwave signal source in military systems, is of special interest to microwave design engineers. Gunn devices operate at high current and high power densities and require the use of adequate heat sinks to maintain safe operating active region temperatures.

For high power devices, a plated heat sinking technique can be used, requiring the plating of a thick (1 to 3 mil) gold layer on the metallized contact layer of the device.

The major failure modes in Gunn devices are associated with high temperature operation. Failure modes usually detected in the early life of the product include hot spot formations caused by cracking at the mesa because of flexing of the plated gold heat sink, micro-cracking caused by the application of the lead wire to the chip, and metallization shorting of the chip excessive bonding pressure. Long term failure mechanisms result from a combination of materials utilized for metallization, contacts, and cooling efficiency of the anode heat sink, resulting in a shorting condition in the device.

3.2 Schottky Diodes

The Schottky-barrier diode has become highly utilized as a microwave detector. It can be constructed using a silicon or GaAs base and has an ohmic contact that may be formed in a number of ways such as whisker contact, C-spring contact or thermocompression bond (See Figure 3). The diode is essentially a metal to semiconductor junction, differing from a P-N junction in which both P and N type semiconductor material are required.

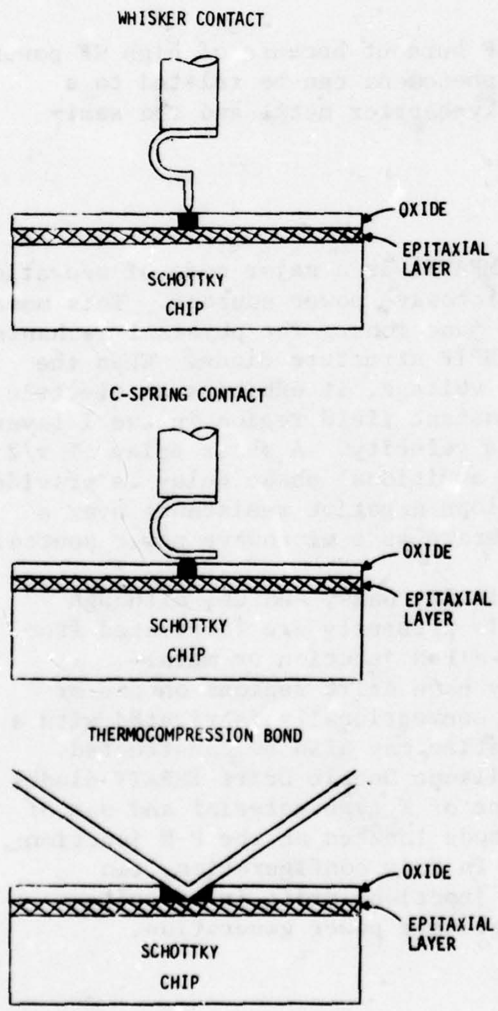


Figure 3. Schottky Barrier Diode Construction

A critical parameter in choosing the semiconductor material in a Schottky diode is the barrier height achieved. The P type semiconductor materials have a barrier height so low that leakage is excessive and in most cases have higher bulk resistivity. For these reasons the P type diode material is not used to fabricate Schottky-barrier devices.

The Schottky diode is fabricated by depositing a metal onto the semiconductor material in a selected small area. Contact is then made to the metal as described previously. The preferred construction is the thermocompression bond which provides a stronger bond during any dynamic environmental exposure.

Schottky diodes are used in microwave circuits as detector and mixer diodes. In the application as a detector, the Schottky diode demonstrates a lower noise level than the point contact diode, provides a more stable mechanical bond, and has better dynamic range. The point contact diode has a higher burnout capability and higher rectification efficiency at low levels. Schottky mixer diodes are used in the first stage of super-heterodyne converters.

Schottky diodes are susceptible to RF burnout because of high RF power levels for a short period of time. This phenomena can be related to a metallurgical reaction between the Schottky-barrier metal and the semi-conductor material.

3.3 IMPATT Diodes

Impact Avalanche and Transit Time (IMPATT) is a major mode of operation that occurs in avalanche diodes used as microwave power sources. This mode was first observed in 1965 in silicon P-N junctions. The physical mechanism was first proposed by Read for a PNIN or NPIP structure diode. When the diode is subjected to a reverse breakdown voltage, it exhibits an electric field profile at the P-N junction and a constant field region in the I layer, in which holes drift at scattering limited velocity. A phase delay of $\pi/2$ is associated with the avalanche zone and additional phase delay is provided by the drift space. The device then develops negative resistance over a range of frequencies and, as such, can operate as a microwave power source.

IMPATT operation has been developed in Si, GaAs, and Ge, although interest in Ge has not progressed. IMPATTs presently are fabricated from both silicon and GaAs, make use of either a P-N junction or metal-semiconductor (Schottky) junction, and may have drift regions on one or both sides of the junction. The diode is conventionally fabricated with a P+NN+ configuration but an N+PP+ configuration may also be constructed. (Single Drift Diode). In addition, the Silicon Double Drift IMPATT diodes combine two back-to-back drift regions (One of N type material and one of P type material) which share a common cathode located at the P-N junction separating the two halves of the device. In this configuration, two charge clouds, which are generated at the junction, drift in opposite directions and each contributes to the microwave power generation.

IMPATT diodes are fabricated by either growing the junction epitaxially on a substrate or by diffusion techniques. Figure 4 shows a typical IMPATT diode construction with a plated gold heat sink.

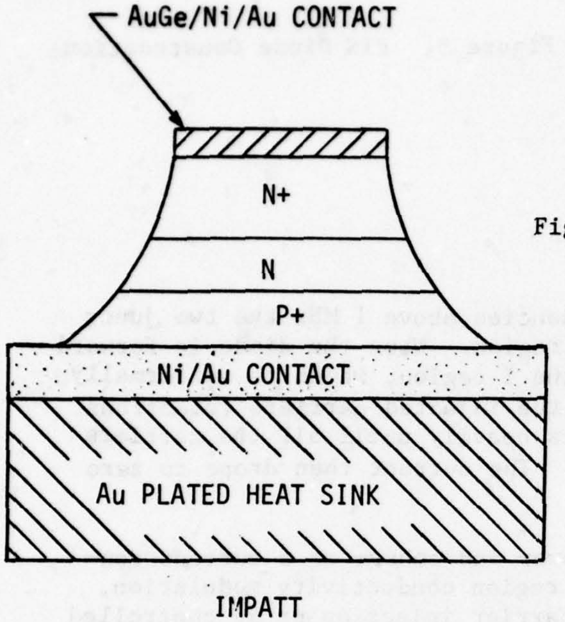


Figure 4. IMPATT Diode Construction

IMPATT diodes are used primarily as oscillators in the microwave and millimeter frequencies. They are capable of producing up to 2 watts of power in the 12-14 GHz frequency range. The millimeter wave IMPATT diodes have been capable of producing power at frequencies up to 340 GHz.

The life of an IMPATT diode is directly related to the junction temperature of the device, which is the most important reliability parameter. There is a linear relationship between input power and junction temperature rise. A failure mode which has been detected in IMPATT diodes has been the diffusion of the contact metal into the semiconductor material, which results in the shorting of the diode. This failure mode may be influenced by the choice of metals used in the contacting system, the control exercised while applying those metals, and the device operating junction temperature. The junction temperature should never exceed 200°C for any long period of time.

3.4 PIN Diodes

PIN diodes are defined as diodes consisting of a P type semiconductor material, an N type semiconductor material, and an intrinsic (base material without doping) semiconductor material sandwiched between the two as shown in Figure 5. The PIN diode is essentially two diodes in series. The resistance of the material between the two junctions (I region), is determined by the number of free carriers injected into it by the two junctions. When there are no carriers, the resistance is high. When the current is between 10 and 100 milliamperes, the I region resistance drops to about 1 ohm. At low frequencies the I region resistance is lower than the two

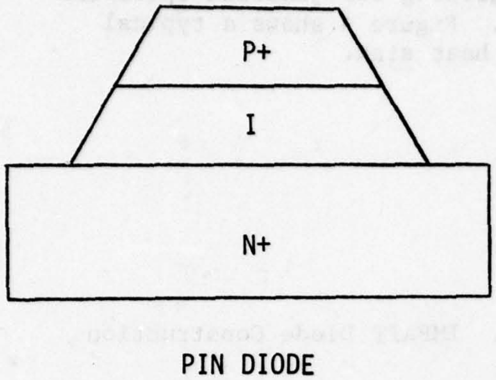


Figure 5. PIN Diode Construction

diode junction resistances, but at frequencies above 1 MHz the two junctions have a lower impedance than the I region. When the diode is forward biased, injected carriers diffuse into the I region, which is uniformally resistive. If reverse bias is applied, the injected carriers (electrons and holes) reverse and the diode conducts heavily until all the carriers have returned to their planes of origin. The current then drops to zero and there is no further conduction.

PIN diodes are used to switch RF power and behave as a current controlled microwave resistor because of I region conductivity modulation, which can be produced by dc controlled carrier injection or RF controlled carrier injection. The PIN diode can control large amounts of RF power with a relatively small consumption of biasing or switching power. Depending on the I region thickness, PINs can be used in limiter circuits, fast switching circuits, digital phase shifters, attenuator and modulator circuits and high power switching circuits.

In switching and phase shifter application, the PIN is either heavily forward biased or heavily reversed biased. Important design parameters are the isolation, insertion loss, and switching times. Values of forward current, reverse voltage and transmission line impedance must be selected so that excessive RF power is not dissipated in the PIN during the switching cycle. The PIN may withstand the RF power at bias states of forward and reverse bias, but the PIN can pass through an impedance level during the transition through the switching states that will cause it to absorb power. If the switching time is too slow, the diode will heat up, causing it ultimately to fail. Junction temperature of a PIN diode should not exceed 175°C.

PIN diodes are fabricated primarily by growing an epitaxial layer on a P+ or N+ substrate. The substrate may be silicon or GaAs. An epitaxial I layer is grown on a P+ substrate and is followed by an N+ layer. Metallization is then applied to the N+ layer and the P+ layer. Mesa devices are formed by chemical etching. PIN diodes, varactor diodes, and IMPATT diodes each utilize similar configurations of two diodes junctions in series. The difference between a varactor diode and PIN diode is in the dimension of the intrinsic material. For varactor diodes the dimension is, in the order of 1/10 mil. For limiter PIN diodes it is about 3/10 mil, and for high power PIN diodes it is 1 to 10 mils.

PIN diodes are classified by the power ratings they meet. The highest power PIN diodes are rated up to 25 kW peak power. Power ratings decrease to medium power devices and small signal devices.

3.5 Gallium Arsenide Field Effect Transistor

The Gallium Arsenide Field Effect Transistor (GaAs FET) has developed into a device which exhibits low noise and outstanding gain and power characteristics and is capable of operating at microwave frequencies up to 40 GHz.

The GaAs FET is a semiconductor whose resistance is controlled by the application of an electric field perpendicular to the direction of current flow. This device is a unipolar device since current is carried by one type of carrier, the majority carrier of the bulk semiconductor material, which drifts along the element, under the action of the electric field applied between its ends. This field is established through ohmic contacts to the ends of the semiconductor elements which are known as the source and the drain. The controlling electric field in the GaAs FET results from the reverse biasing of a metal-semiconductor (Schottky-barrier) junction which forms the gate. A metal-semiconductor Schottky-barrier diode is used for the gate because of the difficulties associated with making a conventional P-N junction in GaAs. (See Figure 6.) In GaAs, electrons move much faster than holes, so GaAs FETs are made only with n type material.

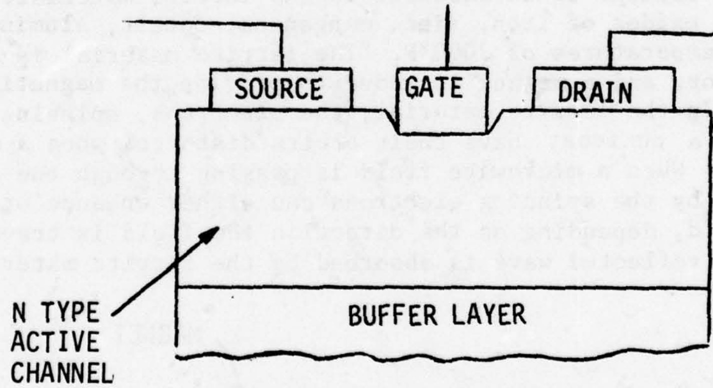


Figure 6. Gallium Arsenide Field Effect Transistor

Gallium Arsenide FETs are constructed by growing three epitaxial layers in sequence. On a semi-insulated substrate a lightly doped buffer layer is grown. Then a moderately doped N type active layer and a highly doped N+ contact layer are added. Portions of the N and N+ layer are removed to form a mesa which will become the active channel of the device. The source and drain electrodes are formed by evaporation of gold-germanium onto the wafer's surface through a photoresist mask. The aluminum gate is patterned directly on the N type active channel between the source and the drain by a second photoresist technique. Wire leads are added at a later time in the process.

As GaAs FETs are pushed to higher frequency limits, the gate lengths must be reduced. The state of the art techniques can produce a gate length of 0.5 microns, but gate lengths of 0.2 microns are being approached. The difficulty is in producing 0.2 micron gates reliably and uniformly with high yields.

Because of small dimensions, GaAs FETs can be damaged or destroyed by large transient voltage spikes. Spike leakage causing a breakdown around the periphery of a gate is a predominant failure mode in a GaAs FET. Spike breakdown causes localized heating resulting in the formation of holes in the channel region. This ultimately results in a catastrophic failure of the device. At high temperature operation metallic migration occurs when the ohmic contact metal moves in the direction of electron flow and causes the metal to short out the device. This failure mode may be reduced in several ways. The metallization may be made thicker, reducing the current density. Rectangular contacts give a more uniform distribution of current flow, thus reducing temperature. The junction temperature can be lowered by reducing thermal impedances and would result in improvements in reliability.

3.6 Isolators, Circulators

An isolator is a device which, when inserted into a microwave circuit, will pass microwave signals in one direction but will inhibit them in the other. The basic element of an isolator is the ferrite material. Ferrites are produced from oxides of iron, zinc, manganese, cobalt, aluminum, or nickel fired at temperatures of 2000°F. The ferrite material is emplaced within the isolator, and a magnet is added to provide the magnetic field. (See Figure 7). In the ferrite material, the electrons, spinning about their axes around a nucleus, have their orbits distorted when a magnetic field is applied. When a microwave field is passing through the isolator, the field created by the spinning electrons can either enhance or cancel the microwave field, depending on the direction the field is traveling. The energy of the reflected wave is absorbed by the ferrite material.

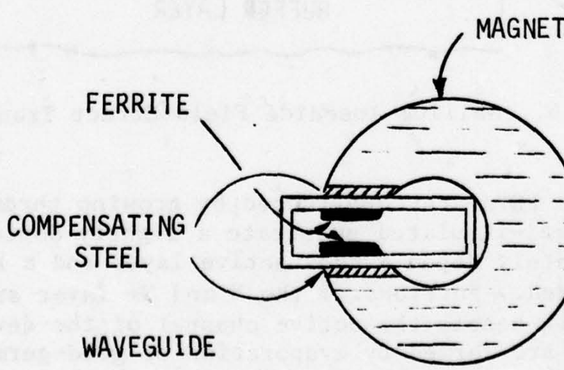


Figure 7. Isolator

Circulators operate on the same basic principles as the isolators. The circulator differs from the isolator in that the RF field moving through the transmission line is bent into the adjoining guide by the polarization effects of the ferrite. The isolation effects are achieved by enhancement in one direction and cancellation in the other.

Circulators are usually three or four port devices, depending on the construction and allow energy to pass in one direction with nominal loss while providing isolation in the other. Figure 8 indicates the flow of microwave energy within a circulator. The microwave signal will pass from a to b, from b to c, and from c to a, with only a nominal insertion loss. Energy in the opposite direction, from b to a, from a to c, or from c to b would be isolated in the order of 25 dB.

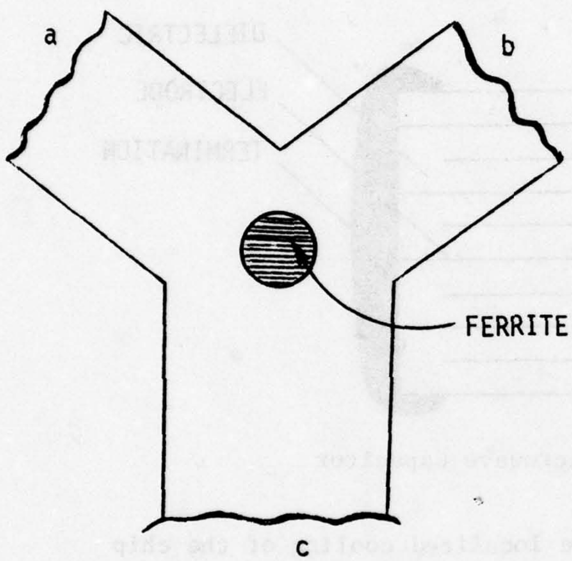


Figure 8. Circulator

Circulators and isolators are available in waveguide, coaxial, and stripline configurations. Each type is dependent on the ferrite operation to provide the proper passage of signals.

3.7 Capacitors

Chip capacitors are being used in microstrip circuitry in such devices as switches, attenuators, oscillators, and mixers.

Three key parameters to be considered in the evaluation of microwave-chip capacitors are insertion loss, quality factor (Q), and RF power capability. In order to meet these requirements, chip capacitors must use low loss dielectrics and high conductivity metal systems.

Insertion loss is defined as the sum of reflective losses caused by impedance mismatch and capacitor dissipative losses. RF power is based on the ability to handle high frequency voltage and current.

Microwave capacitors are designed primarily for use in coupling, by-pass, and dc blocking applications where only a minimum attenuation of the microwave signal can be tolerated. They are constructed by cofiring alternate layers of metal (electrodes) with carefully selected ceramic (Dielectric) materials as shown in Figure 9. Chip capacitors have thermal properties characteristic of ceramic materials. Originally processed at high temperatures, chips can withstand exposure to temperatures limited only by the termination material. Chip capacitors are stronger under compression than under tensile forces. When a chip is cooling, it is under a tensile state of stress. Too rapid a cooling rate creates a temperature gradient across the chip cross section which, if too severe, will cause the chip to fail. Larger units are more prone to thermal shock failures than smaller units because of the increased mass.

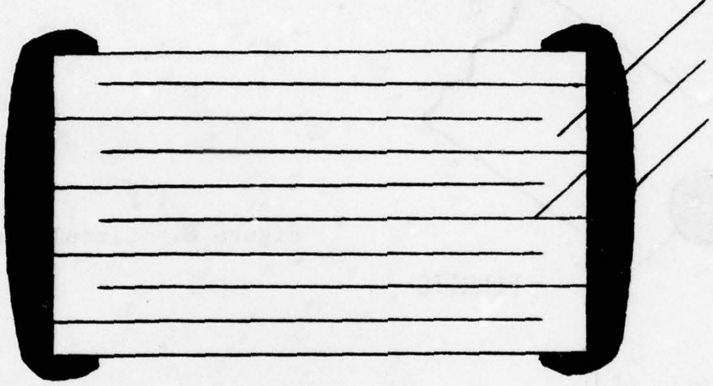


Figure 9. Microwave Capacitor

Leads attached to chip can create localized cooling of the chip surface, generating temperature gradients and tensile forces which might result in failure. Such thermal shock failure is not easily detected. The usual indication is an increase in the dissipation factor because of microcracks in the chip.

3.8 Low Noise Transistors

Low noise transistors are being used in the place of traveling wave tubes in broad-band amplifier operations at microwave frequencies up to 6 GHz. They combine a very low noise figure with high associated gain.

Depending on the manufacturer, low noise transistors are silicon bipolar devices of the planar type constructed with interdigitized, overlay, mesh or diamond type geometries. They may have emitter resistors incorporated to equalize current distributions.

Microwave transistors become conditionally stable after reaching the lower critical frequency. The transistor remains stable at frequencies above the critical frequency until a frequency that is 0.1 times f_t is reached. f_t is defined as the frequency at which hf_e becomes unity.

f_t is proportional to the area of the emitter, which is a limiting factor. Emitter widths are now in the order of 0.5 microns.

The noise figure of the microwave transistor is defined as:

$$\text{Noise Figure (F)} = \frac{\text{Signal to noise ratio at output}}{\text{Signal to noise ratio at input}}$$

Noise generation is the result of shot noise in the emitter, shot noise in the collector, and thermal noise in the base resistance. Typical values of noise figures for low noise transistors range from 2 to 4 dB at between 2 to 6 GHz.

Heat transfer with proper heat sinking is critical to the ultimate performance of the transistor amplifier. All leads must be kept short to reduce inductance and minimize stress on the package. Thermal interfaces must be effective to allow heat transfer from the transistor to the heat sink. The metallization is usually gold, which provides a uniform conductor and improves the operation of the transistor with respect to excessive contact heating, excessive current density, and metal migration. The device is packaged in a hermetically sealed stripline package under an inert atmosphere which protects the transistor chip from moisture and corrosive gases.

Low noise transistors are expected to be used in the design of new systems with small signal amplifiers below 6 GHz utilizing silicon bipolar devices. Large signal amplifiers are also being developed for higher power applications with R&D efforts to develop transistors capable of 65 watts peak output power in S band.

3.9 Ferrite Phase Shifters

Ferrite phase shifters are used in the radiating elements of phased array radar antennas. They are in direct competition with semiconductor phase shifters which have had the edge in usage because of advantages they possess. The ferrite phase shifter, because of high power requirements for the magnetic fields necessary for operation, were not selected in many designs and consequently have seen little field usage.

The development of the latching phase shifter reversed the required power disadvantage because of power is now required only to change the state of the device, not to maintain the state. In comparison of the two devices, the semiconductor phase shifter now requires more power to operate than the latching ferrite device.

The ferrite phase shifter is an analog device which achieves a phase accuracy without increasing the insertion loss of the device. In the digital phase shifter, every bit used adds to the insertion loss of the device and a 9 bit device would have a high loss which would make it prohibitive to use.

The ferrite phase shifter consists of a ferrite section and a driver circuit. The driver circuit contains electronic components such as diodes,

transistors, etc. The ferrite section would contain matching elements, Faraday rotation systems, polarizers, and attenuators.

Ferrite material exhibits one significant deficiency. All samples of ferrite material do not magnetize in the same manner. This becomes a serious problem if interchangeability of parts is required.

Phase shifter requirements differ for various applications. In a ground based system, a maximum range is needed, requiring high RF levels. Weight of the device is not of major impact and modulation rates would not be high. In this application the ferrite phase shifter has the advantages that are considered best. Airborne phased array radar requires medium power levels and high modulation rates. Lightweight equipment is important in the design of the airborne system. Thus the digital phase shifter would be the best choice for this application.

3.10 Loads and Terminations

A dummy load is a high power single terminal device intended to terminate a transmission line. It is primarily used to test high power microwave systems at full power capacity. Low power coaxial loads are generally called terminations and are discussed later.

A dummy load is fabricated from dissipative material which includes:

1 Lossy plastic

2 Refractory material

3 Water.

The lossy plastic consists of particles of lossy material suspended in plastic medium. This material is used primarily for low frequency and low power applications and is limited in operating temperature range. The refractory material is a rugged substance that may be operated up to 1600°F. It is fired in finished form and cannot be machined. This material is used in most high power applications. Water loads are used for extremely high power and temperature applications.

Dummy loads are cooled by air convection, forced air cooling, or liquid cooling. In the case of free air cooling, the loads are provided with fins to increase the outer surface area. Forced air cooling is used to provide greater heat transfer for higher power ratings. Liquid cooled loads use water or other coolants in direct contact with the load housing to optimize heat transfer and dissipation.

Dummy loads are rated from low power (0.1 watt) to high powered units (up to 20 kW average power). They operate in the microwave frequencies up to 40 GHz.

Terminations are low power single terminal devices intended to terminate a transmission line. They are employed to terminate slotted lines for standing wave ratio measurements and as reference loads on directional

couplers, hybrid junctions and power devices. They are used as dummy antennas and terminal loads for impedance measurements of transmission devices such as filters and attenuators.

The resistive elements in these terminations are developed for use at microwave frequencies. They are resistive film center conductors and molded resistive tapers. The resistive film is thin compared to the skin depth and electrically very short at the highest operating frequency. The molded taper consists of a dissipative material evenly dispersed in a properly cured dielectric medium.

Power ratings range from average power (0.1 watt) to high power (200 watts). These terminations are usually operated in free air, but extended heat sinking and/or forced air cooling may be used to increase the power rating capability.

3.11 Surface Acoustic Wave Device

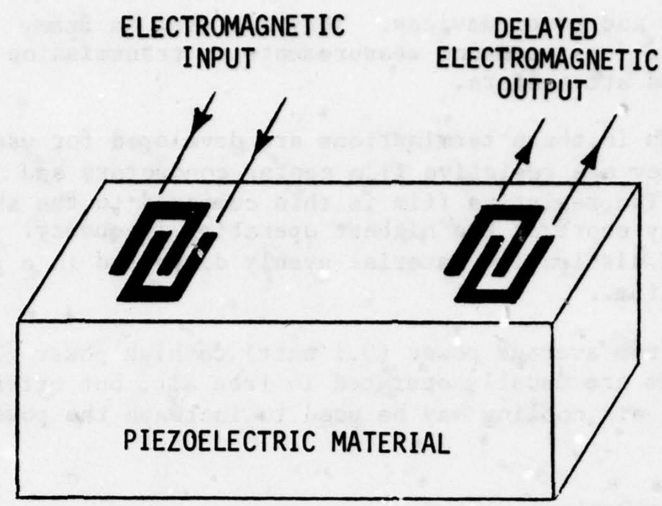
Surface acoustic wave (SAW) devices are used principally in radar, communications or electronic warfare systems. Initially they performed as dispersive filters for radar-pulse compression and phase coded, tapped delay line filters for PSK waveforms in spread spectrum communications, and they were further developed into oscillators, band pass filters, and variable delay lines.

SAW devices are composed of two key elements (see Figure 10). The first element is the piezoelectric substrate, which supports the acoustic wave and the second element is the interdigital transducer (IDT), both input and output, which provide time delay of the acoustic signal. The IDT is a metallic structure, composed of electrodes which are spaced on centers equal to one half of the SAW wavelength. Aluminum and gold are the metals most often used for IDTS in SAW devices. A thin layer of chrome or titanium is sometimes used to promote adherence between the aluminum or gold and the substrate. The adherence layer is almost always required for gold on an oxide type substrate. The metal is deposited on the substrate by evaporation from a resistance-heated filament, evaporation from an electron-beam-heated crucible, or RF sputtering. The metallic pattern is then defined by chemical etching, electron-beam lithography of X-ray lithography.

The piezoelectric element is a crystal, usually lithium niobate, ($LiNbO_3$) or quartz (SiO_2). Other materials that are being developed are lithium tantalate ($LiTaO_3$), bismuth germanium oxide (BGO) and bismuth silicon oxide (BSO). The substrate material must be grown, cut, and polished to eliminate poor orientation, surface defects and surface roughness, all of which degrade the performance of the device.

Connections to the IDTS are made with thermocompression bond techniques with the wire material usually gold or aluminum.

SAW devices are presently available in frequencies of up to 1 GHz, because of the limitations of the optical lithography and the surface



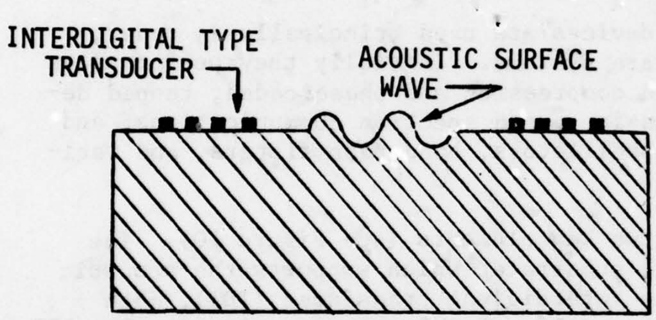


Figure 10. Surface Acoustic Wave Device

acoustic wave velocity of SiO_2 and $LiNbO_3$. Materials now being studied may raise the limit to 2 GHz.

$LiNbO_3$ has a large temperature coefficient of time delay which necessitates the use of ovens or other techniques for temperature control. The long term stability of SAW devices is presently being investigated. Initial observations indicate an aging effect which degrades the device over a long period of time. This appears to be associated with contaminants within the SAW material.

SAW devices are sensitive to equipment transients and electrostatic charge buildup. When metal melting occurs because of high voltage transients but does not result in a shorted condition, a surface irregularity occurs in the substrate which inhibits the acoustic wave. A large number of these irregularities degrade the acoustic wave. If the metal melting has resulted in a shorted condition between the two electrodes, the SAW device would fail catastrophically. This condition does not occur frequently and is not considered to be a major failure mode. Metal rupture breaks electrical continuity and degrades performance. The ratio of damaged to undamaged fingers determines the amount of degradation of the device.

The SAW devices can be protected from excessive damage by developing handling procedures for these components to protect them from people generated electrostatic discharge. Handling equipment must also be grounded, or otherwise designed, to prevent electrostatic induced damage to SAW IDTs.

3.12 Varactor Diodes

Varactor diodes are semiconductor devices characterized by a voltage variable capacitance. They are used as resonant circuit tuners of bulk semiconductor oscillators, as frequency multipliers, and as parametric amplifiers.

Tuning varactor materials include both Si and GaAs. Si is most used because of lower cost, and lower figure of merit applications from HF to microwave frequencies. Gallium arsenide is used when high operating frequencies require the highest figure of merit possible, as in parametric amplifiers and millimeter frequency multipliers.

Tuning diodes, step recovery diodes and PIN diodes are all made in the same configuration; i.e., a P-N junction, a carefully controlled epitaxial layer and a very low resistance substrate. The main differences between these devices are the resistivity and thickness of the epitaxial layer. Tuning diodes require epitaxial or intrinsic layers where both the resistivity and thickness are carefully controlled. Step recovery and PIN diodes require I regions of controlled thickness, but resistivity of the I region is not critical, as long as it is high.

The varactor diode is an abrupt junction diode, in which the P+ region of the diode is much more highly doped than the I region, with the high doping falling to the I region doping in a distance that is short compared to the thickness of the I layer. As a result of the properties of the P-N junction, a depletion layer is formed between the P and N regions whose width depends on the voltage applied to the diode. The capacitance of the diode is inversely proportional to the width of the depletion layer. Thus, as the diode reverse bias is changed, the capacitance varies accordingly.

Microwave tuning diodes are constructed using the mesa processing technique (Figure 11). This method is preferred over the planar construction because it provides a higher figure of merit and lower series resistance in the varactor diode.

Varactor diodes exhibit a long term post tuning drift which is caused by a reverse impurity ion-build up around the junction over a long period of time under reverse bias. This condition may be reduced by applying a heavy passivation layer around the junction or by reducing the exposed area.

There are limitations on the capacitance change in the device which must be considered in circuit requirements. As the reverse voltage on the diode increases, the capacitance decreases because of a widening of the depletion layer. If the depletion layer widens as the complete I region is

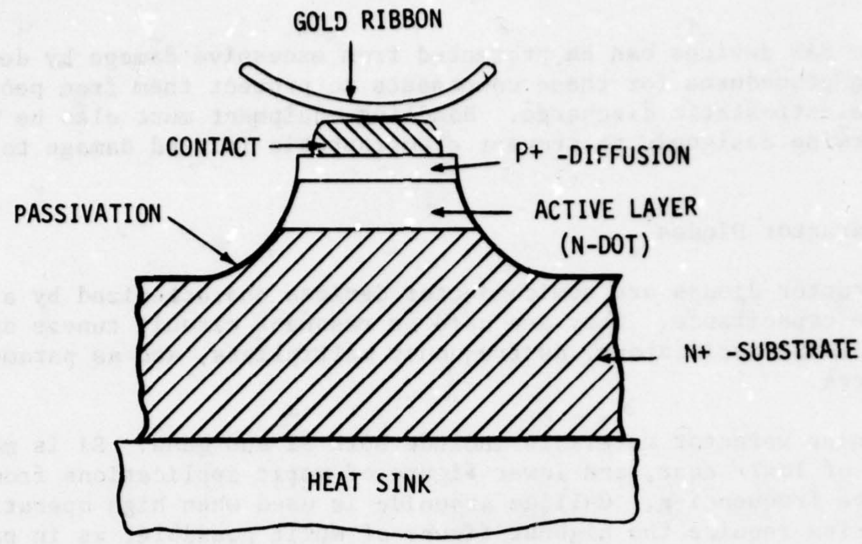


Figure 11. Varactor MESA Construction

depleted, the capacitance will not change further with an increase of voltage. This condition is called voltage punch through. If the electric field exceeds the dielectric strength of the semiconductor material, avalanche current is drawn. If more than a few milliamperes of current are drawn, localized overheating may destroy the diode. This condition is called the breakdown voltage of the diode, which must be calculated with accuracy to establish the maximum capability of the diode.

3.13 YIG Filters

YIG filters are passive devices, designed to tune microwave cavities and microwave oscillators. They consist of one or more spheres made of yttrium iron garnet (YIG) mounted on a mechanically stable nonconducting rod that locates the sphere in its optimum position within a magnetic field and with relationship to the coupling loop. (Figure 12). They operate over a microwave frequency range up to 18 GHz.

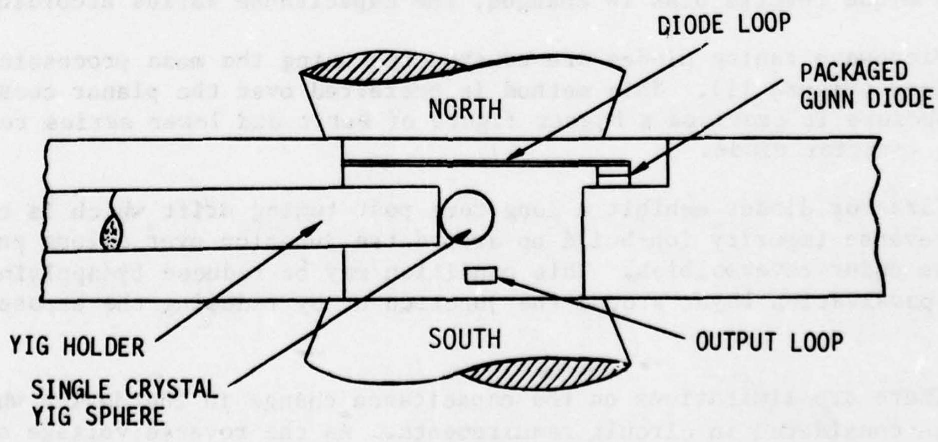


Figure 12. YIG Tuned Gunn Oscillator

A YIG sphere operates on the principle of spin resonance in the crystalline structure. A YIG sphere is placed in a magnetic field, which results in resonance. Coupling is accomplished through apertures or loops where there is a strong coupling at frequencies of sphere resonance and minimal coupling at other frequencies. The resonant frequency is regulated by the strength of the magnetic field.

In operation, the temperature of the YIG sphere is controlled by heaters which maintain a minimum temperature drift, thus reducing frequency drift. YIG spheres, subjected to mechanical stresses, could suffer fracture of the bond of the sphere to the tuning rod. Electrically, the spheres, functioning as magnetic resonant circuits, are not subject to electrical overstress. They are not prone to electrical burnout.

4.0 DATA ANALYSIS

4.1 Statistical Analysis

As part of this study, data were collected on the 13 categories of microwave solid state devices. The data were analyzed and summarized in the form of failure rates for the individual devices. Basic ground rules and assumptions were established for these analyses, along with rules defining statistical tests for combining the data. Numerical examples are given for the statistical tests and the calculation of failure rates.

4.2 Calculation of Failure Rates

All failure rates were calculated at the upper single-sided 60 percent confidence level. Before calculating the failure rates, data were identified as time or failure truncated. As far as could be determined, no failure truncated data were received. All data were assumed to be time truncated. The upper confidence level failure rate was calculated by using the device part-hours and the 40 percent chi-squared value at 2r + 2 degrees of freedom. If the data had been failure truncated, the value would have been obtained at 2r degrees of freedom.

The general equation used for calculating the failure rate was obtained from Reference 1 and is:

$$\frac{X^2\ (\alpha,\ 2r + 2)}{2T} = \text{Upper single-sided confidence limit}$$

Where r = the number of failures and determines the degree of freedom coordinate used in determining the Chi-squared value.

X^2 = Chi-squared value

2r + 2 = Total number of degrees of freedom

α = Acceptable risk of error (40 percent in this study)

1 - α = Confidence level (60 percent in this study)

T = Total number of device part-hours

As an example, assume that one failure occurred during 55.72 x 16^6 part-hours of ground fixed environment. These data were used to calculate the failure rate at the upper single-sided 60 percent confidence level on

PIN diodes. A table from Reference 1 was used as the source of the Chi-squared value:

$$\text{Failure Rate (60 percent confidence)} = \frac{X^2\ (0.40,\ 4)}{2T} = \frac{4.04}{111.44 \times 10^6}$$

Failure Rate (60 percent confidence) = 0.036 failures/10^6 hours

Since the reference statistical tables are limited to Chi-squared values up to 100 degrees of freedom, it was necessary to calculate an estimate of the Chi-squared percentile points whenever more than 49 failures were observed in the data. In accordance with reference 1, confidence level values are approximated by:

$$Xp^2 = 1/2\ (Zp + \sqrt{2f-1})^2$$

Where:

Xp^2 = approximated Chi-squared value

and

f = total number of degrees of freedom

Zp = 0.25335 and is the value of the standard normal variable at the 60 percent significance level.

Using data from dummy loads rated over 100 watts, which was in the ground fixed environment, which had 61 failures in 77.11 x 10^6 part-hours of operation, the failure rate is calculated as:

$$\text{Failure Rate (60 percent confidence)} = \frac{1/2\ (0.25335 + \sqrt{(2 \times 61) - 1})^2}{2(77.11 \times 10^6)}$$

Failure Rate (60 percent confidence) = 0.8235 failures/10^6 hours

4.3 Device Classification and Failure Rates

Field operational data and laboratory test data were collected for microwave solid state devices as utilized in military equipment. The data were studied, analyzed, and categorized by specific type and environmental application. Results of the data collection are shown in Tables 4-1 through 4-10. No component testing was performed to obtain data, but an extensive data survey and collection effort was undertaken to locate and obtain necessary data. Components studied were typical of those used in military ground, airborne, satellite, ground mobile, and shipboard applications.

The data listed are in the form of failures per million hours and are calcuated at the point estimate where failures occurred, and also at the 60 percent upper confidence level for all categories. Failure rates were not calculated when less than 1.0 million part-hours of data were collected. The environmental factors are the same as listed in MIL-HDBK-217B.

Component failure is defined as the inability of the part to perform its intended function, resulting in its repair or replacement. When detailed failure information was available, all secondary failures, premature removals, and procedural, and personnel errors were censored.

TABLE 4-1

Summary of Operating Data Collected on
Isolators by Environment

Environment	Device Part Hours ($x10^6$)	Failures	Failure Rate (failures/10^6 hrs.) Point Estimate	60% Confidence
N_S	0.051723	0	-------	-----
G_F	1.811	0	-------	0.505
G_M	0.0104	0	-------	-----
S_F	2.988	0	-------	0.306
Total	4.85	0		

TABLE 4-2

Summary of Operating Data Collected on
Dummy Loads and Terminations by Environment and Power Rating

Environment	Power Rating	Device Part Hours ($x10^6$)	Failures	Failure Rate (failures/10^6 hrs.) Point Estimate	60% Confidence
G_F	<100W	80.0427	0	-------	0.011
G_F	>100W	76.03923	61	0.8	0.838
G_F	Water Cooled	1.92128	2	1.04	1.05
N_S	<100W	0.007389	0	-------	-----
G_F	Termi-nation	1.017418	0	-------	0.899
Total		159.028	63		

TABLE 4-3

Summary of Operating Data Collected on
Ferrite Circulators by Environment

Environment	Device Part Hours ($x10^6$)	Failures	Failure Rate (failures/10^6 hrs.) Point Estimate	60% Confidence
N_S	0.007389	0		-----
G_F	5.80364	0	-------	0.158
G_M	0.0104	0	-------	-----
Total	5.8214	0		

Since most of the data obtained listed only the quantity of failures and experience with no elaboration of failure modes and mechanisms, much of the data are dependent on the sources ability to properly categorize their equipment failure. As a result of direct contact with most of the sources, the majority of data contributed to this study were judged to have been properly screened by contributors.

TABLE 4-4

Summary of Operating Data Collected on Microwave Capacitors by Environment

Environment	Device Part Hours ($x10^6$)	Failures	Failure Rate (failures/10^6 hrs.)	
			Point Estimate	60% Confidence
G_F	2.53	2	0.79	1.187

TABLE 4-5

Summary of Operating Data Collected on Ferrite Phase Shifters by Environment

Environment	Device Part Hours ($x10^6$)	Failures	Failure Rate (failures/10^6 hrs.)	
			Point Estimate	60% Confidence
G_F	3.407	0	-------	0.2685

TABLE 4-6

Summary of Operating Data Collected on Low Noise Transistors by Environment

Environment	Device Part Hours ($x10^6$)	Failures	Failure Rate (failures/10^6 hrs.)	
			Point Estimate	60% Confidence
Temperature Cycling	3.285	0	-------	0.2785

TABLE 4-7

Summary of Operating Data Collected on
PIN Diodes by Type and Environment

Part Quality	Environment	Power Rating	Device Part Hours($x10^6$)	Failures	Failure Rate (failures/10^6 hrs.) Point Estimate	60% Confidence
JAN	G_F	High	8291.84	1298	0.1565	0.1577
Commercial	G_F	Low	10.150642	2	0.197	0.296
Commercial	G_F	Low	63.054	25	0.396	0.427
Commercial	G_F	Low	14.17	0	------	0.037
JAN	Reliab. Demo	Low	0.588549	0	------	-----
JAN	Reliab. Demo	Low	0.01077	0	------	-----
Commercial	G_M	Low	0.0208	0	------	-----
Commercial	G_F	Low	57.7719	1	0.017	0.035
		Total	8462.24	1326		

TABLE 4-8

Summary of Operating Data Collected on
Schottky Diodes by Environment

Environment	Device Part Hours ($x10^6$)	Failures	Failure Rate (failures/10^6 hrs.) Point Estimate	60% Confidence
N_S	16.546778	1	0.0605	0.122
G_F	1.503	0	------	0.598
G_M	1.4163	0	------	0.646
G_F	31.16	1	0.032	0.065
G_F	2.248623	0	------	0.407
S_F	0.12817	0	------	-----
Lunar Surface	0.157	0	------	-----
Reliab. Demo	4.1818	1	0.239	0.483
50°C Rel Test	0.413336	0	------	-----
In-house	3.319992	0	------	0.275
In-house	0.072566	0	------	-----
55°C Rel Test	0.091239	0	------	-----
Total	61.23	3		

TABLE 4-9

Summary of Operating Data Collected on
Couplers by Environment

Environment	Device Part Hours (x10^6)	Failures	Failure Rate (failures/10^6 hrs.)	
			Point Estimate	60% Confidence
N_S	0.014778	0	------	-----
G_F	0.82274	0	------	-----
G_F	10.56	18	1.704	1.875
Total	11.397518	18		

TABLE 4-10

Summary of Operating Data Collected on
Varactor Diodes by Environment

Environment	Device Part Hours (x10^6)	Failures	Failure Rate (failures/10^6 hrs.)	
			Point Estimate	60% Confidence
Reliab. Demo	0.02788	0	------	-----
G_F	2.583	0	------	0.354
S_F	35.17	0	------	0.026
Reliab. Demo	0.809	0	------	-----
Lunar Surface	0.0336	0	------	-----
N_S	0.091239	0	------	0.833
Total	38.71	0		

5.0 FAILURE RATE MODELS

Failure rate models for microwave solid state devices were derived from field data collected during this study, from laboratory data collected during this study, from references in literature collected during this study and from expert engineering opinions. In areas where reliability prediction models are presently described in MIL-HDBK-217B, a comparison is made between those failure rates and the newly derived failure rates.

5.1 Gunn Diode Failure Rate Prediction Model

5.1.1 Basic Failure Rate (λ_b) Evaluation for Gunn Diodes

No field operating data were available on Gunn diodes during the study program. There have been data collected during laboratory life tests on the devices by research laboratories and device manufacturers. The reliability prediction model and base failure rate were developed from these data and expert engineering judgment.

A report (See Reference 1) describes a life test program which had accumulated a total of 868,000 device hours. In addition an oscillator test program has accumulated over 440,000 hours of Gunn diode operating time. An operating life test on medium power Gunn diodes has accumulated 461,000 hours operating time with no failures occurring (See Reference 2). The MTBF for these devices is reported between 153,900 hours and 8.9 x 10^6 hours. A report from a device manufacturer (See Reference 3) has accumulated operating time on several types of Gunn diodes. This data were collected during a life test program and is as shown in Table 5-1.

TABLE 5-1

Gunn Diode Life Test Data

(GHz) Frequency Band	Operating Voltage	Device Hours	Failure	MTTF 90% Confidence
4-8	13	118,000	0	50,000
8-12	15	300,000	2	65,000
	10	1,114,000	4	200,000
	13	1,809,000	29	90,000
12-18	10	1,112,000	4	200,000
18-26	8	274,000	1	75,000

Another life test program (See Reference 4) has accumulated over 10,000 hours with no failures being observed.

The data collected in this study for Gunn diodes were not sufficient to permit an exact mathematical derivation of a base failure rate with a high degree of confidence. However, a failure rate of between 6 failures/10^6 hours and 0.11 failures/10^6 hours can be calculated for these devices. A failure rate of 0.7 failures/10^6 hours at 60 percent confidence has been demonstrated from life test data in Reference 4. The base failure rate was therefore been estimated at 0.7 failures/10^6 hours. For Gunn diodes based on the limited data available and engineering judgment.

5.1.2 Environmental Factor (π_E) Evaluation for Gunn Diodes

There is no reliability prediction model in MIL-HDBK-217B for Gunn diodes. The environmental factors for diodes in each of the other similar groups of semiconductor diodes are essentially the same. The environmental factors for Gunn diodes have been assumed to be the same and are as shown in Table 5-2.

TABLE 5-2

Environmental Factors (π_E) for Gunn Diodes

Environment	π_E
G_B	1
S_F	1
G_F	5
N_S	10
A_{IT}	12
A_{UT}	20
G_M	25
N_U	25
A_{IF}	25
A_{UF}	40
M_L	40

5.1.3 Reliability Prediction Model for Gunn Diodes

The reliability operating data collected on Gunn diodes during this study are not varied enough to allow the development of a base failure rate equation. Therefore the reliability prediction model will be an average failure rate. The average failure rate for Gunn diodes is 0.7 failures/10^6 hours. The reliability prediction model is as shown below:

$$\lambda_p = \lambda_b(\pi_E \times \pi_p)$$

Where λ_b = Base Failure Rate (0.7 failures/10^6 hours)
π_E = Environmental Factor
π_p = Power Rating Factor

5.1.4 Evaluation of the Power Rating Factor (π_P) for Gunn Diodes

Gunn diodes are rated as low power, medium power or high power devices. Low power devices are those devices rated less than 40 Mw. Medium and high power devices are rated from 40 mW to 1W. Because of higher thermal stresses of the higher power devices the reliability is reduced. A factor of 1 has been taken as the base for low powered devices. A factor of 2 has been estimated for medium and high powered devices which are estimated to have twice the stress of the lowered power devices.

5.2 Schottky Diode Failure Rate Prediction Model

5.2.1 Schottky Diode Failure Rate (λ_b) Evaluation

Failure rates were calculated for Schottky diodes in each environment for which sufficient data has been collected. Operating failure rates for each set of data were calculated at point estimate (where failures have occurred) and at the 60 percent confidence level in every case. Results of these calculations are summarized in table 5-3. The failure rates calculated at the 60 percent confidence level are used for comparisons and further computations presented in this report.

TABLE 5-3

(Schottky Diodes)
Observed Failure Rate
(Failures/Million Hours)

Environment	Quality Grade	Ambient Temperature	Stress	Failure Rate
G_F	Commercial	30°C	10%	0.065
G_F	JAN	25°C	30%	0.598
G_F	JAN	40°C	50%	0.417
N_S	JAN	30°C	50%	0.122

There is no reliability prediction model in MIL-HDBK-217B for Schottky diodes. Presently the model for microwave diodes must be used. The model and base failure rates are shown in Section 2.2.7 of the Handbook. Since Schottky diodes are microwave mixer or detector diodes, specified to MIL-S-19500, the microwave diode basic model will apply to the Schottky diode as follows:

$$\lambda_P = \lambda_b \times \pi_E \times \pi_Q$$

Where λ_b = Base Failure Rate

π_E = Environmental Factor

π_Q = Quality Factor

The microwave diode quality factor, π_Q, is taken from Table 2.2.7-2 of MIL-HDBK-217B as follows:

Quality Level	π_Q
JAN TXV	1.0
JAN TX	2.0
JAN	3.5
Lower	5.0

If the observed field operating failure rates are normalized by the π_Q factors for microwave diodes, the normalized field failure rates become as shown in Table 5-4.

TABLE 5-4

Schottky Diodes
Observed Failure Rates Normalized by π_Q Factor
(Failures/Million Hours)

Environment	(Quality)	Failure Rate
G_F	(Commercial)	0.013
G_F	(JAN)	0.171
G_F	(JAN)	0.119
N_S	(JAN)	0.035

The environmental factors, π_E, for microwave diodes are listed in Table 2.2.7-1 of MIL-HDBK-217B (as ammended by Reference 5) and are as follows:

Environment	π_E
G_B	1
S_F	1
G_F	10
N_S	15
A_{IT}	25
A_{UT}	40
G_M	50
N_U	50
A_{IF}	50
A_{UF}	80
M_L	200

If the failure rates of Table 5-4 are further normalized by the microwave diodes π_E factors of MIL-HDBK-217B, the field operating failure rates become as shown in Table 5-5.

TABLE 5-5

Schottky Diodes
Observed Field Operating Failure Rates
Normalized by π_E and π_Q Factors
(Failures/Million Hours)

Ambient Temperature °C	Stress Percent	Failure Rate
30	10	0.0013
25	30	0.017
40	50	0.0119
30	50	0.0023

Using the failure rates of Table 5-4 and the equation for base failure rates of semiconductors listed on page 2.2-2 of MIL-HDBK-217B,

$$\lambda_b = Ae^{\left(\frac{NT}{273 + T + (\Delta t)\ S}\right)} e^{\left(\frac{273 + T + (\Delta t)\ S}{TM}\right)^P}$$

and assuming all constants to be the same, with the exception of A, the value of the constant A can then be determined to be 0.005.

The reliability prediction model for Schottky diodes then is as follows:

$$\lambda_P = \lambda_b \times \pi_E \times \pi_Q$$

Where λ_b = Base Failure Rate (See Table in Appendix B)

π_E = Environmental Factor (See Table 2.2.7-1, MIL-HDBK-217B)

π_Q = Quality Factor (See Table 2.2.7-2, MIL-HDBK-217B)

5.3 IMPATT Diode Failure Rate Prediction Model

5.3.1 Basic Failure Rate (λ_b) Evaluation for IMPATT Diodes

No field operating data were available on IMPATT diodes during the study program. There have been data collected from laboratory life tests and reliability tests conducted on this device by research laboratories and device manufacturers. The reliability prediction model and base failure rates have been developed from this data and expert engineering opinion.

IMPATT diodes operate at high current densities. Their junction temperatures are nominally 200°C. Diode thermal conductance is a critical parameter in producing reliable IMPATT diodes. One test program (See Reference 6) accumulated 70,000 devices hours with one failure. The MTBF for those devices was calculated at greater than 23,500 hours.

Another study of Silicon IMPATT diode has a design target of 3.3×10^6 hours MTBF. This study (See Reference 7) has predicted an MTBF of $>10^8$ hours at a unction temperature of 200°C. Reliability data of accelerated stress tests (See Reference 8) indicates an MTBF of 10^7 hours at 198°C junction temperature. Reliability studies (See Reference 9) have shown GaAs IMPATT diodes to exhibit an MTBF of 2×10^6 hours at 200°C junction temperature.

A report of fixed junction temperature operating test on Si and GaAs IMPATT diodes (See Reference 10) indicates a median life for Si IMPATT diodes of over 435,000 hours at a junction temperature of 200°C. Reliability tests conducted on Si double drift and single draft IMPATT diodes (See Reference 11) predicts a failure rate for Si IMPATT diodes to be between 6 and 1.0 failures/10^6 hours. A report (See Reference 12) extropolates the MTBF for Si IMPATT diodes to be 2×10^6 hours at 200°C junction temperature.

From the data accumulated in the accelerated stress tests and operational life tests, a base failure rate of 0.5 failures/10^6 hours has been developed for IMPATT diodes at room temperature and 50 percent stress.

5.3.2 Environmental Factor (π_E) for IMPATT Diodes

For IMPATT diodes, in the same category as Group VII diodes, the assumption that the same environmental factors as the other Group VIII diodes apply, has been made. There are no operational data that would indicate otherwise. These factors are shown in Table 5-6 (See Reference 13).

TABLE 5-6

Environmental Factors (π_E) for IMPATT Diodes

Environment	π_E
G_B	1
S_F	1
G_F	5
N_S	10
A_{IT}	12
A_{UT}	20
G_M	25
N_U	25
A_{IF}	25
A_{UF}	40
M_L	40

5.3.3 Evaluation of Quality Factor (π_Q) for IMPATT Diodes

Table 2.2.8-2 of MIL-HDBK-217B lists the quality factors that are used in the mathematical model for Group VIII diodes. This Table is applicable to the mathematical model for IMPATT diodes and is as shown in Table 5-7.

TABLE 5-7

Quality Factors (π_Q) for IMPATT Diodes

Quality Level	π_Q
JAN TXV	0.5
JAN TX	1.0
JAN	5.0
Lower	25.0

5.3.4 Reliability Prediction Model for IMPATT Diodes

IMPATT diodes are in the same category as PIN diodes and Varactor diodes. The reliability prediction mathematical model is then postulated to be the same form as that of the Group VIII diode. This model is presented below:

$$\lambda_p = \lambda_b(\pi_E \times \pi_Q) \text{ failures}/10^6 \text{ hours}$$

Where λ_b = Base Failure Rate (See Table Appendix B)

π_E = Environmental Factor (See Table 2.2.8-1, MIL-HDBK-217B)

π_Q = Quality Factor (See Table 2.2.8-2, MIL-HDBK-217B)

Table 2.2-2 in MIL-HDBK-217B will be modified to include the following data, based on the failure rates developed in Section 5.3.1.

GROUP	PART TYPE	A	N_T	T_M	P	Δt_f
VIII	IMPATT	10.57	-1162	448	13.8	150

5.4 PIN Diode Failure Rate Prediction Model

5.4.1 Base Failure Rate Evaluation for PIN Diodes

Failure rates were calculated for PIN diodes in each environment for which sufficient data had been collected. Each set of data was categorized within environment by power rating (high power, medium power, or low power). Operating failure rates for each set of data were calculated at the 60 percent confidence level. Results of these calculations are summarized in Table 5-8. The failure rates calculated at the 60 percent

confidence level are used for comparisons and further computations presented in this report.

TABLE 5-8

PIN Diodes Observed Failure Rate
(Failures/Million Hours)

Environment	Power Rating	Quality	Failure Rate
G_F	High Power	JAN	0.1577
G_F	Low Power	Commercial	0.427
G_F	Low Power	Commercial	0.296
G_F	Low Power	Commercial	0.0645
S_F	Low Power	JAN	0.037
G_F	Low Power	Commercial	0.035

There is no reliability prediction model for PIN diodes presently in MIL-HDBK-217B. PIN diodes are similar in construction to Varactor diodes and this model was chosen for comparison. The model for Varactor diodes is shown in Section 2.2.8 and is as follows:

$\lambda_P = \lambda_b \ (\pi_E \times \pi_Q)$
λ_b = Base Failure Rate
π_E = Environmental Factor
π_Q = Quality Factor

The Quality Factor, π_Q, for Varactor diodes, as listed in Table 2.2.8-2 of the MIL-HDBK-217B is as follows:

Quality Level	π_Q
JAN TXV	0.5
JAN TX	1.0
JAN	5.0
Lower	25.0

If the observed failure rates are normalized by the π_Q factors for Varactor diodes, the observed failure rates become as shown in Table 5-9:

TABLE 5-9

PIN Diodes
Observed Failure Rates Normalized by π_Q Factor

	(Failures/Million Hours)	
Environment	Power Rating	Failure Rate
G_F	High Power	0.0315
G_F	Low Power	0.017
G_F	Low Power	0.012
G_F	Low Power	0.0026
S_F	Low Power	0.007
G_F	Low Power	0.0014

The Environmental Factors, π_E, for Varactor diodes are listed in Table 2.2.8-1. (See Reference 13a) are as follows:

Environment	π_E
G_F	1
S_F	1
G_F	5
N_S	10
A_{IT}	12
A_{UT}	20
G_M	25
N_U	25
A_{IF}	25
A_{UF}	40
M_L	40

If the observed failure rates are further normalized by the π_E factors for Varactor diodes, the observed failure rates become as shown in Table 5-10.

TABLE 5-10

PIN Diodes

Observed Failure Rates Normalized by π_E and π_Q Factors

Ambient Temperature (°C)	Stress (percent)	Power Rating	Failure Rate
25	50	High	0.0063
55	50	Low	0.0034
30	30	Low	0.0024
30	10	Low	0.0005
25	10	Low	0.0070
		Low	0.0028

Comparison of the failure rates as developed in this study versus those in MIL-HDBK 217B are shown in Table 5-11. The comparison is made at ambient temperature and stress levels for which data are available.

TABLE 5-11

PIN Diodes

Comparison of Field Failure Rates to MIL-HDBK-217B Failure Rates

Ambient Temperature	Stress	Field Operating Failure Rates	MIL-HDBK-217B Failure Rates	Ratio Field 217B
25	50	0.0063	0.044	7
55	50	0.0034	0.065	19
30	30	0.0024	0.040	19
30	10	0.0005	0.024	48
25	10	0.0070	0.022	3.2
		0.0028		

In each case the base failure rate calculated in this study was lower than that presented in MIL-HDBK-217B. After technical consultation with semiconductor experts at Martin Marietta Corporation, it is believed the failure rate determined is lower than the actual failure rate. Semiconductor specialists estimated the failure rate of PIN used to be the same or greater than that of varactor diodes. Therefore the factor for constant A in Table 2.2-2 in MIL-HDBK-217B has been established to be 0.47 based upon equivocation of device similarity and expert opinion and the Table will be as follows:

Part Type	A	N	T	P	T
PIN	0.47	-1162	448	13.8	150

The Reliability Prediction model for PIN diodes must contain one more factor to account for the variations in low, medium, and high power devices. This factor π_p is the power rating factor. In reviewing of the data and comparing the base failure rates of low to high power devices, the observation has been made that high power devices have approximately four times the failure rate of low power devices. Medium power devices, for which no data have been observed, have been established as three times based upon an assumption of linearity of failure rates between the low, medium, and high power devices given that the failure modes are identical. The power rating factor for PIN diodes should be as shown in Table 5-12.

TABLE 5-12

PIN Diodes
Power Rating Factor (π_p)

Power Rating	π_p
<10W	1.0
10W - <100W	2.0
100W $\leq$1 kW	3.0
>1 KW	4.0

The Reliability Prediction Model for PIN diodes can now be constructed as follows:

$$\lambda_p = \lambda_b\ (\pi_E \times \pi_Q \times \pi_P)$$

Where

λ_b = Base Failure Rate
π_E = Environmental Factor
π_Q = Quality Factor
π_P = Power Rating Factor

5.5 GaAs FET Failure Rate Prediction Model

5.5.1 Base Failure Rate (λ_b) Evaluation for GaAs FETs

No field operating data were available on GaAs FETs during the study program. Many test programs have been conducted on GaAs FETs by research laboratories and device manufacturers. The reliability prediction

model and base failure rates have been developed from this data and expert engineering opinion.

In a study of small signal GaAs FETs (Reference 14) an MTTF is predicted in excess of 10^7 hours at a junction temperature of 70°C. A second study (Reference 15) predicts the MTTF of GaAs FETs to be 10^9 hours at a junction temperature of 80°C.

A report on a solid state amplifier study for power amplifiers (Reference 16) indicates a range of from 1.6×10^7 hours to 3.6×10^7 hours MTBF for 3 types of power GaAs FETs at 150°C junction temperature. A test conducted on twenty devices, operated at a junction temperature of 125°C for 1000 hours was completed with no catastrophic failures (See Reference 17). One report, evaluating three types of devices, predicts an MTBF of 10^8 hours at junction temperatures of 100°C (See Reference 18). A study of low noise microwave GaAs FETs shows the predicted MTBF for the devices to be 2×10^8 hours at 100°C (See Reference 19). From an evaluation of these reports it becomes evident that various manufacturers, using different designs and processes for manufacturing the devices, produce reliability data which varies very much and lacks uniformity. The failure rate to be developed then requires an evaluation of the data available and engineering judgment in the determination of the reliability of the device. Junction temperatures obtained are a result of thermal conductivity of the device, the amount of current adjusted in the device and the ambient temperature of the air around the device. Nominal operating junction temperature is in the order of 150°C. If it is considered that devices operated at 150°C junction temperature have a predicted MTBF of between 0.03×10^6 hours and 5×10^7 hours dependent on the type of device, then a value of 5×10^6 hours can be postulate for a GaAs FET that was operated at a 25°C ambient temperature and a 50 percent stress. This results in a failure rate of 0.2 failures/10^6 hours at that one point (See Reference 20). This in turn correlates with design requirements for GaAs FETs, requiring a failure rate of 200 fits for the GaAs FETs utilized in their system.

5.5.2 Quality Factor (π_Q) Evaluation for GaAs FETs

The quality factors for Silicon FETs are listed in Table 2.2.2-4 of MIL-HDBK-217B. The factors listed are applicable to the GaAs FET and will be used in the model for GaAs FETs as follows in Table 5-13.

TABLE 5-13

Quality Factor (π_Q) for GaAs FETs

Quality Level	π_Q
JAN TXV	0.12
JAN TX	0.24
JAN	1.2
Lower	6.0

5.5.3 Environmental Factor (π_E) for GaAs FETs

The environmental factors for Si FETs are listed in Table 2.2.2-1 of MIL-HDBK-217B. Since no operating field data on GaAs FETs, were available for the study the environmental factors for Si FETs have been assumed to be the same as those of GaAs FETs because of construction and device type similarities and will be taken as applicable to GaAs FETs as shown in Table 5-14 (Reference 21).

TABLE 5-14

Environmental Factors (π_E) for GaAs FETs

Environment	π_E
G_B	1
S_F	1
G_F	5
N_S	10
A_{IT}	12
A_{UT}	20
G_M	25
N_U	25
A_{IF}	25
A_{UF}	40
M_L	40

5.5.4 Power Rating Factor (π_P) for GaAs FETs

Power GaAs FETs are maturing to a point where they are being considered for usage in long term programs. In these applications they may produce up to 2.5 watts at 8 GHz, and the state of the art has advanced so that reliable devices are being produced on a consistant basis rather than sporadac. A power FET is defined as a device producing a linear output of at least 100 mW. Many different designs and geometries are used to produce the devices. It is therefore necessary to incorporate a factor for power GaAs FETs into the reliability prediction model. Because of a minimum amount of available data and the fact that the power FET is still evolving, a factor of 10 times has been chosen as the π_P for GaAs FETs.

5.5.5 Reliability Prediction Model for GaAs FETs

There is no reliability prediction model in MIL-HDBK-217B for GaAs FETs although Section 2.2-2 contains a part failure rate model for Silicon FETs. The model for Silicon FETs is shown below:

$$\lambda_p = \lambda_p(\pi_E \times \pi_A \times \pi_Q \times \pi_C) \text{ failures}/10^6 \text{ hours.}$$

Where λ_b = Base Failure Rate
π_E = Environmental Factor
π_A = Application Factor
π_Q = Quality Factor
π_C = Complexity Factor

The model for Silicon FETs will apply to GaAs FETs with the exception of the application factor (π_A) and complexity factor (π_C). Since the GaAs FET is used only at microwave frequencies, the π_A (5.0) at these frequencies has been incorporated into the base failure rate. The complexity factor is considered for only single devices herein and is equal to one. The power rating factor is added to the model and the reliability prediction model for GaAs FETs is as follows:

$$\lambda_p = \lambda_b (\pi_E \times \pi_Q \times \pi_P)$$

Where λ_b = Base Failure Rate
λ_E = Environmental Factor
π_Q = Quality Factor
π_p = Power Rating Factor

The base failure rate equation parameters in Table 2.2-2 must be changed to reflect the following constants, based on the failure rates developed for GaAs FETs

GROUP	PART TYPE	A	N_T	T_M	P	Δt_f
Group II	GaAS FET	3.6	-1162	448	13.8	150

5.6 Failure Rate Prediction Models for Isolators and Circulators

5.6.1 Basic Failure Rate (λ_b) Evaluation for Isolators and Circulators

Operating field data were collected on isolators and circulators in two environmental categories: Ground Fixed and Space Flight. The devices reported were ferrite devices used in waveguide microwave circuits. Data on stripline circulators were not found during the study. Operating failure rates for each set of data were calculated at the 60 percent confidence level for two categories. No failures were observed in this field data and the failure rates were determined with a limited amount of operating hours. Table 5-15 summarizes these calculations. Ferrite isolators and circulators are constructed in the same manner and a circulator may be converted into an isolator by the addition of terminations within the device. Therefore the two devices were combined and will have one basic failure rate and reliability prediction model. The failure rate calculated at the 60 percent confidence level is used for comparisons and further calculations presented in this report.

There presently is no model in MIL-HDBK-217B to predict the failure rate of an isolator or circulator. Section 2.13 lists an average failure rate of 20 per million hours in Table 2.13-1 (Average Failure Rate for Miscellaneous Parts). In comparing that failure rate to the one calculated in Table 5-15, it is obvious that the field operating failure rate has been significantly improved.

In order to develop a mathematical model that will predict the failure rate of ferrite isolators and circulators, the parameters that affect the reliability of the devices must be determined. Environmental

TABLE 5-15

Isolators/Circulators Observed Failure Rate
(Failures/Million Hours)

Environment		Failure Rate
	Isolator	
G_F S_F		0.505 0.306
	Circulator	
G_F		0.158

influence in one factor to be considered. Since the ferrite devices are basically passive, absorbing energy where required, the basic mechanical structure must be examined. The devices are bonded together and are capable of withstanding environmental stresses readily. Environmental factors that would affect the device are vibration, shock, temperature, and moisture.

The second factor that must be considered in the development of a reliability mathematical model is the factor associated with the power rating of the device. As power ratings increase, temperatures increase and voltage breakdown within the device is possible.

The model for the reliability prediction of ferrite circulators and isolators becomes:

$$\lambda_P = \lambda_b \, (\pi_E \times \pi_P)$$

Where λ_P = failure rate of the device

λ_b = Base Failure Rate

π_E = Environmental factor

π_P = Power Rating Factor

5.6.2 Environmental Factor Evaluation for Isolators and Circulators

Examination of the data collected in this study indicates the Space Flight environmental failure rate for isolators is almost half that of the failure rate for the ground fixed environment. This is essentially because there are more hours collected in the Space Flight environment and no failures have occurred in either case. Therefore a more reasonable approach is to assume that environmental factors for similar type devices are applicable to ferrite isolators and circulators. Similar devices such as transformers and other inductive devices utilize factors which are applicable to circulators and isolators and are shown in Table 5-16.

TABLE 5-16

Environmental Factors (π_E) for Circulators and Isolators

Environment	Π_E
G_B	1.0
S_F	1.0
G_F	2.0
N_S	5.0
A_{IT}	5.0
A_{UT}	6.0
G_M	6.0
N_U	7.0
A_{IF}	7.0
A_{UF}	10.0
M_L	10.0

5.6.3 Power Rating Factor Evaluation for Isolators and Circulators

The power rating factor (π_p) of isolators and circulators cannot be directly determined from the data collected in this study. High power devices can be considered to be those rated at average power of 100W and over. Inherently devices which dissipate a large amount of power will be less reliable than the low power device since data were collected on high power devices during this study, a factor of two for π_p has been assumed based on engineering judgement for isolators and circulators rated greater than 100W.

5.6.4 Reliability Prediction Model for Isolators and Circulators

Since the failure rate observed for circulators in a ground fixed environment was 0.158 failures/10^6 hours, with the greatest amount of data collected in this set, and similar failure rates calculated for other ferrite devices was 0.2 failures/10^6 hours, the failure rate for circulators and isolators should also be set at 0.2 failures/10^6 hours.

The reliability prediction model for isolators and circulators is as follows:

$\lambda_p = \lambda_b \ (\pi_E \times \pi_p)$ failures/10^6 hours

Where $\lambda_b =$ 0.2 failures/10^6 hours

$\pi_E =$ Environmental Factor (See Table Appendix B)

$\pi_p =$ Power Rating Factor (See Para 5.6.3)

5.7 Microwave Capacitor Failure Rate Prediction Model

5.7.1 Base Failure Rate Evaluation for Microwave Capacitors

Field operating data were collected for microwave capacitors in the ground fixed environment only. A total of 2.53×10^6 operating hours were recorded on microwave capacitors in phase shifter operation. Two failures were reported during this time. Operating failure rates for this set of data were calculated at the 60 percent confidence level. The failure rate for microwave capacitors was calculated to be 1.22 failures/10^6 hours. Because of device construction and simularity, the environmental factors for ceramic type capacitors are assumed to be similar and are shown in Table 5-17 (Reference 22).

TABLE 5-17

Environmental Factors (π_E) for Ceramic Capacitors

Environment	π_E
G_B	1
S_F	1
G_F	2
N_S	2.5
G_M	6
N_U	18
A_{UT}	24
A_{IT}	6
M_L	30
A_{IF}	12
A_{UF}	48

This set of environmental factors will be assumed applicable to the microwave capacitors. Normalizing the failure rate calculated for microwave capacitors by the environmental factor for G_F, the base failure rate for microwave capacitors becomes 0.61 failures/10^6 hours. Since no other data were collected during the study program to further define the parameters affecting the reliability of the microwave capacitors, the reliability prediction model will be as follows:

$$\lambda_p = \lambda_b \times \pi_E$$

Where λ_b = base failure rate (0.6 failures/10^6 hours)

π_E = Environmental Factor (See Table Appendix B)

5.8 Low Noise Transistor Failure Rate Prediction Model

5.8.1 Base Failure Rate (λ_b) Evaluation for Low Noise Transistor

No field operating data were available on low noise transistors during this study. Data were collected from a report on a temperature cycling and vibration test program on NPN low noise transistors installed in an electronic system. There was a total of 3.284966×10^6 hours of operating time accumulated with zero failures. This results in a failure rate of 0.278 failures per million hours.

Based upon the simularity of design material, and construction of low noise NPN microwave transistors to that of silicon NPN transistors, the reliability prediction model already contained in section 2.2.1 of MIL-HDBK-217B can be assumed as applicable and has been used as follows:

$$\lambda_p = \lambda_b(\pi_E \times \pi_A \times \pi_Q \times \pi_{S2} \times \pi_C \times \pi_R)$$

Where λ_b = base failure rate
λ_E = Environmental Factor
π_A = Application Factor
π_Q = Quality Factor
π_{S2} = Voltage Stress Factor
π_C = Complexity Factor
π_R = Power Rating (watts)

The Quality factor, π_Q, for silicon NPN Transistors can also be considered as applicable. The most recent π_Q is as listed in Table 2.2.1-3 of Reference 23 and is as follows:

Quality Level	π_Q
JAN TXV	0.12
JAN TX	0.24
JAN	1.2
Lower	6.0
Plastic	12.0

If the field failure rate for low noise transistors (0.278×10^6) of this study is normalized by the π_Q factor for JAN TX parts, the base failure rate becomes 1.158 failures/10^6 hours for JAN parts. Since no other data were available during this study, qualify factors for silicon NPN transistors will be used for low noise transistors.

The application factor for low noise transistors will be that factor associated with frequencies above 400 MHz. This will be equivalent to a factor of 5. If the base failure rate is normalized by this factor, the base failure rate becomes 0.231 failures/10^6 hours.

Voltage stress is not known for this data set but will be presumed to be not greater than 50 percent. The π_{S2} factor for 50 percent is 0.04 (See Reference 24). By normalization, the base failure rate becomes 0.361 failures/10^6 hours.

The environmental factor π_E, cannot be assigned directly to any of the established categories. From other experience a temperature cycling and vibration environment would be expected to be more severe than ground fixed, but not as severe as airborne inhabited. A π_E factor of 10 would be applicable to determine the effect of the environment on the device. If the base failure rate is further normalized by this factor, it becomes 0.0361 failures/10^6 hours.

5.8.2 Reliability Prediction Model for Low Noise Transistors.

Since the application of low noise transistors is above 400 MHz, the π_A factor for silicon NPN transistors should be incorporated into the base failure rate. This would increase the base failure rate to 0.1805 failures/10^6 hours. The reliability prediction model for single silicon bipolar low noise transistors would then become:

$$\lambda_p = \lambda_b(\pi_E \times \pi_Q \times \pi_R \times \pi_{S2})$$

Where each factor is as shown in MIL-HDBK-217B for silicon transistors. Table 2.2-2 should contain a new section as follows:

GROUP	PART TYPE	A	N_T	T_M	P	Δt_f
Transistors I	Low Noise Transistors	2.00	-1052	448	10.5	150

5.9 Ferrite Phase Shifter Failure Rate Prediction Model

5.9.1 Basic Failure Rate (λ_b) Evaluation for Ferrite Phase Shifters

Operating field data were available and collected on ferrite phase shifters in only one environmental category: ground fixed. The devices reported were ferrite phase shifters with driver circuits. Only the ferrite portion of the phase shifter was considered in this analysis. The operating failure rate for these data was calculated at the 60 percent confidence level. No failures were observed in this field data for the ferrite device. Table 5-18 summarizes the failure rate calculation. The failure rate calculated at the 60 percent confidence level is used for comparison and further calculations presented in this report.

TABLE 5-18

Ferrite Phase Shifter
Observed Failure Rate
(Failures/Million Hours)

Environment	Failure Rate
Ground Fixed	0.2685

There presently is no model in MIL-HDBK-217B to predict the failure rate of a ferrite phase shifter. Section 2.13 lists an average failure rate of 20 failures per million hours in Table 2.13-1 (Average Failure Rate for Miscellaneous Parts). Data from operating field conditions indicate the failure rate is significantly lower. ($0.2685/10^6$ hours.) This base failure rate has been calculated for a ground fixed environmnet and an ambient temperature of 30°C.

5.9.2 Environmental Factor (π_E) Evaluation for Ferrite Phase Shifters

Ferrite phase shifters are passive devices, which react to microwave signals processed through them. They are similar in construction to ferrite circulators and isolators. The environmental factors which are applicable to circulators and isolators can therefore be also taken as applicable to ferrite phase shifters and are as follows:

TABLE 5-19

Environmental Factors (π_E) for
Ferrite Phase Shifters

Environment	π_E
S_F	1.0
G_B	1.0
G_F	2.0
N_S	5.0
A_{IT}	5.0
A_{UT}	6.0
G_M	6.0
N_U	7.0
A_{IF}	7.0
A_{UF}	10.0
M_L	10.0

5.9.3 Reliability Prediction Model for Ferrite Phase Shifter

The base failure rate for ferrite phase shifters in the ground fixed environment is 0.2685 failures per million hours. Since the environmental factor for ground fixed environments is 2.0, the base failure rate for ferrite phase shifters would then be 0.134 failures/10^6 hours or approximately 0.15 failures/10^6 hours. The reliability prediction model for ferrite phase shifters becomes:

$$\lambda_P = \lambda_b \times \pi_E$$

Where $\lambda_b =$ 0.15 failures/million hours

$\pi_E =$ Environmental Factor (See Table Appendix B)

5.10 Failure Rate Prediction Models for Loads and Terminations.

5.10.1 Base Failure Rate (λ_b) Evaluation for loads and terminations.

Dummy loads and terminations have been categorized by power level.

Operating failure rates for each set of data were calculated for the 60 percent confidence level in every case. Results of these calculations are summarized in Table 5-20. The failure rates calculated at the 60 percent confidence level have been used for comparisons and further calculations presented in this report.

TABLE 5-20

Loads and Terminations
Observed Failure Rate
(Failures/Million Hours)

Environment	Power Rating	Failure Rate
G_F	<100W	0.011
G_F	>100W	0.838
G_F	Water Cooled	1.05
G_F	Termination	0.899

5.10.2 Evaluation of the Environmental Factor (π_E)

Loads and terminations are presently listed in MIL-HDBK-217B in Table 2.13-1 under average failure rates for Miscellaneous Parts. Based on engineering judgement and similarity of construction, the method used to calculate the failure rate π_E factors for loads and terminations has been taken to be the same as that used to calculate the failure rate of the appropriate power film resistor. These factors are shown as follows (see Reference 25).

Environment	π_E
G_B	1
S_F	1
G_F	2
N_S	2
G_M	6
A_{IT}	6
A_{IF}	12
N_U	13.5
A_{UT}	15
A_{UF}	30
M_L	35

5.10.3 Reliability Prediction Model for Loads and Termination.

All data collected in this study were for the ground fixed environment, thus alleviating comparison to other environments for this device. When the environmental factor, π_E, for ground fixed environments is applied, the base failure rates are reduced by a factor of 2 and normalized as shown in Table 5-21.

TABLE 5-21

Loads
Observed Failure Rates Normalized by π_E Factor
(Failures/Million Hours)

Environment	Power Rating	λ_b
G_F	<100W	0.0055
G_F	>100W	0.419
G_F	Water Cooled	0.525
G_F	Termination	0.449

From the observed failure rate data of Table 5-21 the power rating of the dummy load can be seen to have a significant impact on the failure rate. The ratio between watercooled (high power) and low power devices is also observed to be approximately 100:1. π_P (power rating) factors have been derived and are as shown in Table 5-22.

TABLE 5-22

Loads
Power Rating Factor π_P

Power Rating	π_P
<100W	1
100W - 1kW	50
>1kW	100

The reliability prediction model for dummy loads is:

$$\lambda_P = \lambda_b\ (\pi_E \times \pi_P)$$

Where λ_b = base failure rate (0.005 failures/10^6 hr)
π_E = Environmental factor (See Table Appendix B)
π_P = Power rating factor (See Table Appendix B)

5.10.4 Reliability Prediction Model for Terminations

Data was available and collected in the ground fixed environment for terminations. Based on the data collected, the observed failure rate is approximately the same as those for the mid-power dummy loads.

Because of the construction and other design similarities the reliability prediction model for terminations can be taken to be the same as the model used for dummy loads. The π_P factor as derived from the field data is 50. The postulated model for termination then becomes:

$$\lambda_P = \lambda_b\ (\pi_E \times \pi_P)$$

Where

λ_b = base failure rate (0.005 failures/10^6 hours)
π_E = Environmental factor (See Table Appendix B)
π_P = Termination Power rating factor (50)

5.11 SAW Failure Rate Prediction Models

5.11.1 Basic Failure Rate (λ_b) Evaluation of Surface Acoustic Wave Devices

No field operating data were available or collected on SAW devices. It therefore became necessary to evaluate the reliability of SAW devices based on comparison to reliability and life test data of similar devices. SAW devices used to delay microwave signals are basically passive devices with input and output transducers bonded to a crystalline structure. Based on this, the most important modifier needed in the reliability model would be an environmental factor π_E. Not enough data or experience exist to justify or define other factors such as π_P. The reliability prediction model for SAW devices has then been postulated as follows:

$$\lambda_P = \lambda_b \times \pi_E$$

Where λ_b = base failure rate

π_E = environmental factor

There is presently no failure rate or reliability prediction model for SAW devices in MIL-HDBK-217B. A failure rate has been defined for Quartz Crystals in Table 2.13-1 (Average Failure Rates for Miscellaneous Parts). The failure rate for quartz crystals is 0.2 failures/million hours. References 24 and 25 describe life tests performed on SAW devices that demonstrate an MTBF in excess of 10^6 hours. Reference 26 states that the temperature stability of SAW devices is comparable to that achieved in crystals. Based on the above data, the base failure rate for SAW devices should be similar to that of Quartz Crystals. (0.2 failures/million hours).

Basic SAW device structures affected very little functionally by shock or vibration in the expected military environment. Leads and bonding of the IDTs, however, are affected to a greater degree by vibration and shock inputs. Temperature stability exhibited by SAW devices is approaching that of Quartz Crystal. The environmental factor, based on conditions developed for each environment with respect to the dynamic and static conditions should be as shown in Table 5-23.

TABLE 5-23

Environmental Factor (π_E) for SAW Devices

Environment	π_E
S_F	1.0
G_B	1.0
G_F	2.0
G_M	3.0
A_{IT}	5.0
N_S	5.0
A_{IF}	6.0
A_{UT}	7.0
N_U	7.0
A_{UF}	8.0
M_L	10.0

5.12 Varactor Diode Failure Rate Model

5.12.1 Varactor Diode Base Failure Rate (λ_b) Evaluation

Field operating data were available and collected on Varactor diodes in several environmental categories. The devices, for which data were reported, were varactor tuning diodes but not frequency multiplier diodes. No data were available collected on varactor diodes used as frequency multipliers. The oeprating failure rates for this data were calculated at the 60 percent confidence level since no failures were observed in the field data on varactor diodes. Table 5-24 summarizes the failure rate calculation. The failure rate calculated at the 60 percent confidence level is used for comparison and further calculations presented in this report.

TABLE 5-24

Varactor Diode
Observed Failure Rate
(Failures/Million Hours)

Environment	Failure Rate
S_F	0.026
G_F	0.354
N_S	0.833

Reliability prediction models and failure rates for varactor diodes are presently specified in Section 2.2.8 MIL-HDBK-217B. The varactor model is:

$$\lambda_P = \lambda_b \times \pi_E \times \pi_Q$$

Where λ_b = Base failure rate (Table 2.2.8-3 MIL-HDBK-217B)

π_E = Environmental Factor (Table 2.2.8-1 MIL-HDBK-217B)

π_Q = Quality Factor (Table 2.2.8-2 MIL-HDBK-217B)

The Quality Factor, π_Q, for Varactor diodes is listed in Table 2.2.8-2 in MIL-HDBK-217B as follows:

Quality Level	π_Q
JAN TXV	0.5
JAN TX	1.0
JAN	5.0
Lower	25.0

If the failure rates calculated from the field operating data are normalized by the Quality factors shown above, the field operating failure rates become as shown in Table 5-25.

TABLE 5-25

Field Operating Failure Rates
Normalized by π_Q Factor

Environment	Quality	Failure Rate
G_F	JAN	0.071
S_F	JAN TX	0.026
N_S	JAN	0.166

The environmental factor π_E for Varactor diodes as listed in Table 2.2.8-1 and modified in Reference 27 are as follows:

Environment	π_E
G_B	1
S_F	1
G_F	5
N_S	10
A_{IT}	12
A_{UT}	20
G_M	25
N_U	25
A_{IF}	25
A_{UF}	40
M_L	40

If the field operating failure rates are normalized by the factors listed above, the failure rates become as shown in Table 5-26.

TABLE 5-26

Field Operating Failure Rates Normalized by π_Q and π_E Factors
(Failures/Million Hours)

Ambient Temperatures °C	Stress Percent	Failure Rate
20	50	0.014
25	50	0.026
25	50	0.016

When the normalized values of the field data are compared to the operating failure rates predicted in MIL-HDBK-217B for similar temperature and stress conditions, the comparison is shown in Table 5-27.

TABLE 5-27

Varactor Diode
Comparison of Field Failure Rates to MIL-HDBK-217B Predicted Failure Rates
(Failures/Million Hours)

Ambient Temperatures °C	Stress Percent	Field Operating Failure Rates	MIL-HDBK-217B Failure Rates	Ratio
20	50	0.014	0.042	3.0
25	50	0.026	0.044	1.7
25	50	0.016	0.044	2.8

In each case, the base failure rate for data collected in this study was 2 or 3 times lower than that based on failure rate calculation by current MIL-HDBK-217B methods and data. Based on the data shown in Table 5-27, the failure rate for Varactor diodes has been reduced by a factor of 2 from the base failure rate. The factor for the constant A in Table 2.2.2 in MIL-HDBK-217B should become 0.47.

The collected data are insufficient as a mathematical base to determine if the varactor environmental or quality factors should be changed; therefore, the factors that are presently in MIL-HDBK-217B have been assumed to be valid since no experience to amend refute items are available. Only the base failure rate for Varactor diodes will be modified.

Varactor diodes are used in two distinct applications; tuning diodes and frequency multiplier diodes. Although no data were available for frequency multiplying applications, a factor, based on engineering judgement and expert opinion, has been developed and is applicable to the varactor diode model as a factor of five to one for multiplier diodes compared to tuning diodes.

The Reliability Prediction model for Varactor diodes then becomes:

$$\lambda_P = \lambda_b \ (\pi_E \times \pi_Q \times \pi_A)$$

Where λ_b = Base failure rate (See Table 2.2.8-3, Appendix B)

π_E = Environmental Factor (See Table 2.2.8-1 MIL-HDBK-217B)

π_Q = Quality Factor (See Table 2.2.8-2 MIL-HDBK-217B)

π_A = Application Factor (See Table, Appendix B)

5.13 YIG Failure Rate Prediction Models

5.13.1 Basic Failure Rate (λ_b) Evaluation of YIG Filters

No field operating data were available or collected on YIG filters. Evaluation of the reliability of YIG filters was done by examining the structure, design, material, and operation of the device and comparing these to other components to establish similarity. YIG filters are passive devices that are generally used with a microwave generation source (Gunn diode, IMPATT diode, etc.). They consist of a sphere of YIG material bonded to a nonmagnetic rod and placed in a microwave cavity within a magnetic field. YIG filters absorb microwave energy at resonant frequencies that are determined by the magnetic field surrounding the cavity. The failure rate and model was necessarily limited to the YIG device proper and not the complete oscillator. The reliability prediction model was then postulated to be similar to ferrite circulators and isolators as follows:

$$\lambda_P = \lambda_b \times \pi_E$$

Where λ_b = base failure rate

π_E = Environmental Factor

5.13.2 Environmental Factor Evaluation for YIG Filters

The basic configuration of a YIG filter is similar to that of other ferrite devices that function in a magnetic field. The environmental factors used for the other ferrite devices can then be presumed to be applicable to the YIG filter. These are shown in Table 5-28.

TABLE 5-28

YIG Filter
Environmental Factors (π_E)

Environment	π_E
S_F	1.0
G_B	1.0
G_F	2.0
G_M	3.0
A_{IT}	5.0
N_S	5.0
A_{IF}	6.0
A_{UT}	7.0
N_U	7.0
A_{UF}	8.0
M_L	10.0

5.13.3 Reliability Prediction Model for YIG Filters

YIG filters are passive devices which operate at resonant frequencies that are determined by the magnetic field surrounding them. The orientation and placement of the rods with the YIG sphere bonded to it within the cavity are critical to proper operation. The base failure rate has been therefore taken to be similar to that of other ferrite devices in this study. In the case of isolators and circulators, the base failure rate is 0.2 failures/10^6 hours and can be assumed for YIG filters based on similarity. The reliability prediction model is:

$$\lambda_P = \lambda_b \times \pi_E$$

Where λ_b = 0.2 failures/10^6 hours

π_E = Environmental Factor (See Table 5-24)

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

More than 8.75 billion part hours have been collected during the contract study program. This data base was used to prepare reliability prediction models and base failure rates for microwave solid state devices for MIL-HDBK-217B.

Several categories and subcategories of microwave devices were either low population devices or so newly developed that adequate field military experience was neither available or of sufficient quantity to mathematically derive base failure rates and factors nor fully validate the reliability models. Limited resources tended to inhibit information from potential sources because of costs associated with internal data accumulation and preparation on the part of the sources. These sources, for proprietary reasons, could also not permit free access to their internal records to the Martin Marietta investigators.

For all such microwave devices that adequate field data were lacking, a combination of expert engineering experience and opinion, along with laboratory and vendor data were used to develop the mathematical models and failure rates.

A large percentage of the total data on microwave diodes (PIN, Varactor and Schottky) were collected during the study. Base failure rates and reliability mathematical models developed in these categories were able to be compared to those presently listed in MIL-HDBK-217B for Varactor diodes. The recently observed field operating failure rates indicate a 2 to 3 times improvement from the currently shown failure rates. The reliability prediction models and failure rates have been revised accordingly for inclusion into a future revision of MIL-HDBK-217B.

Ferrite devices (circulators, isolators, Ferrite Phase Shifters), dummy loads and terminations are listed as small use items in MIL-HDBK-217B under miscellaneous parts. Individual failure rate models and base failure rates have been developed for these devices. These indicate an improvement over the currently shown failure rates in MIL-HDBK-217B.

YIG filters, SAW devices and microwave capacitors are not listed in in MIL-HDBK-217B. The reliability models and base failure rates were developed for future inclusion into MIL-HDBK-217B.

GaAs FETs and low noise transistor devices are based on older and more widespread technology. These devices can be and have been compared to devices already existing in MIL-HDBK-217B. Observed GaAs FET failure rates have been compared to the failure rates developed for Silicon FETs as listed in MIL-HDBK-217B and found slightly higher than those of silicon FETs. Low noise transistors at microwave frequencies have been found to exhibit a higher failure rate than the conventional silicon NPN type transistor.

The other active devices in this study (Gunn diodes and IMPATT diodes) are not presently found in MIL-HDBK-217B. Since no comparable model or base failure rate is in MIL-HDBK-217B, devices have had new models developed for inclusion in a futhre revision to the handbook.

The microwave solid state devices studied in this program are representative of two categories. The first category is composed of devices that have been used in large quantities for radar systems and had been in field operating usage for many years. For these devices, the data base was adequate to develop failure rates having an excellent statistical basis. The second category is composed of microwave devices that in which the state of the art is still evolving and for which failure rates have been developed based on expert judgement and device similarity.

Many innovations and technology changes occurred during the course of this study program. Materials and techniques were developed that may well lead to enhancement of reliability of the individual devices. Because the devices in this category are low population devices once the state-of-the-art is still evolving, the developed faulure rates and mathematical models are conservative. It is felt that future studies of the reliability of these devices will most probably result in and indicate a significant improvement in the values derived in this study. The data base that will be available in the future will permit the calculation of failure rates having a greater degree of statistical confidence and credibility.

6.2 Recommendations

1. The failure rates and reliability prediction models developed in this study should be incorporated into the appropriate sections of MIL-HDBK-217B.

2. A continuing effort to collect reliability data in the areas of microwave solid state devices should be made. Areas in which device technological improvement occurs should be noted and should be monitored so that any increase or decrease in the corresponding level of reliability attainment can be determined.

3. Future studies in the reliability of microwave solid state devices should be concentrated in specific areas of interest. A particular study might be concerned with only active devices; a second would investigate the passive or ferrite devices. This would permit a greater concentration of resources on much fewer devices and hopefully result in a greater amount of data collected and analyzed so that statistically significant quantification of the base failure rates and factors would result.

APPENDIX A

Data Sources

Aerojet Electrosystems
Azuza, California

Aertech Industries
Sunnyvale, California

Bendix Communications Division
Towson, Maryland

Comsat Corporation
Clarksburg, Maryland

GHz Devices
So. Chelmsford, Massachussetts

GTE Sylvania
Needham Heights, Massachussetts

Hylectronics Corporation
Littleton, Massachussetts

Hughes Research Center
Torrance, California

Litton Data Systems
Pascagoula, Mississippi

Microwave Associates
Burlington, Massachussetts

Parametric Industries
Winchester, Massachussetts

P&H Laboratories
Chatsworth, California

Plessey Optoelectronics and Microwave
Irvine, California

Raytheon Company
Wayland, Massachussetts

Teledyne MEC
Palo Alto, California

TRW Semiconductors
Lawndale, California

YIG-Tek Corporation
Santa Clara, California

APPENDIX B

Section
DISCRETE SEMICONDUCTORS Gunn Diodes

Diodes, Group VIII
Gunn Diodes

Part Failure Rate Model (λ_p):

$\lambda_p = \lambda_b \, (\pi_E \times \pi_p)$ failures/10^6 hours

Where
λ_b = Base failure rate (0.7 failures/10^6 hours)
π_E = Environmental Factor (See Table 1)
π_p = Power Rating Factor (See Table 2)

TABLE 1

Environmental Factor π_E

Environment	π_E
G_B	1.0
S_F	1.0
G_F	5.0
N_S	10.0
A_{IT}	12.0
A_{UT}	20.0
G_M	25.0
N_U	25.0
A_{IF}	25.0
A_{UF}	40.0
M_L	40.0

TABLE 2

Power Rating Factor π_P

Power Rating Factor	π_P
$<$ 40 mW	1
$>$ 40 mW	2

Section
SCHOTTKY DIODES

Diodes, Group VII

SPECIFICATION	DESCRIPTION
MIL-S-19500	Schottky Diodes

Part Failure Rate Model (λ_p)

$$\lambda_p = \lambda_b \times \pi_E \times \pi_Q \text{ failures}/10^6 \text{ hours}$$

Where the factors are shown in Tables 1 through 3.

TABLE 1

π_E for Schottky Diodes

Environment	π_E
G_B	1
S_F	1
G_F	10
N_S	15
A_{IT}	25
A_{UT}	40
G_M	50
N_U	50
A_{IF}	50
A_{UF}	80
M_L	200

TABLE 2

π_Q, Quality Factor for Schottky Diodes

Quality Level	π_Q
JANTXV	1.0
JANTX	2.0
JAN	3.5
Lower	5.0

TABLE 3

MIL-S-19500 Diodes, Group VII Silicon Schottky Diode Detectors
Base Failure Rate, λ_b, in Failures per Million Hours

T(°C)	S									
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
0	0.00127	0.00134	0.00142	0.00150	0.00159	0.00168	0.00181	0.00198	0.00224	0.00268
5	0.00130	0.00138	0.00145	0.00154	0.00163	0.00173	0.00187	0.00207	0.00239	0.00296
10	0.00133	0.00141	0.00149	0.00157	0.00167	0.00178	0.00194	0.00218	0.00257	0.00330
15	0.00136	0.00144	0.00152	0.00160	0.00170	0.00184	0.00200	0.00230	0.00281	0.00380
20	0.00139	0.00147	0.00155	0.00164	0.00176	0.00190	0.00210	0.00247	0.00310	0.00445
25	0.00142	0.00150	0.00159	0.00169	0.00178	0.00198	0.00224	0.00269	0.00353	0.00540
30	0.00145	0.00154	0.00162	0.00173	0.00187	0.00200	0.00238	0.00296	0.00410	
35	0.00148	0.00157	0.00166	0.00178	0.00194	0.00218	0.00258	0.00330	0.00490	
40	0.00152	0.00160	0.00170	0.00183	0.00200	0.00230	0.00280	0.00380		
45	0.00155	0.00164	0.00176	0.00190	0.00210	0.00248	0.00310	0.00440		
50	0.00159	0.00168	0.00180	0.00198	0.00220	0.00268	0.00350	0.00538		
55	0.00162	0.00173	0.00187	0.00210	0.00238	0.00296	0.00410			
60	0.00166	0.00178	0.00194	0.00218	0.00258	0.00330	0.00487			
65	0.00170	0.00184	0.00202	0.00230	0.00281	0.00380				
70	0.00175	0.00190	0.00212	0.00247	0.00312	0.00440				
75	0.00180	0.00198	0.00224	0.00269	0.00353	0.00538				
80	0.00187	0.00210	0.00238	0.00295	0.00410					
85	0.00194	0.00218	0.00258	0.00331	0.00487					
90	0.00202	0.00231	0.00281	0.00379						
95	0.00212	0.00248	0.00312	0.00445						
100	0.00224	0.00269	0.00353	0.00538						
105	0.00239	0.00269	0.00409							
110	0.00258	0.00331	0.00487							
115	0.00281	0.00379	0.00560							
120	0.00312	0.00538								
130	0.00409									
135	0.00487									

Section
DISCRETE SEMICONDUCTORS IMPATT Diodes

Diodes, Group VIII
IMPATT Diodes

Part Failure Rate Model (λ_p)

$$\lambda_p = \lambda_b (\pi_E \times \pi_Q) \text{ failures}/10^6 \text{ hours.}$$

Where the factors are shown in Tables 1 through 3.

TABLE 1

π_E for IMPATT Diodes

Environment	π_E
G_B	1.0
S_F	1.0
G_F	5.0
N_S	10.0
A_{IT}	12.0
A_{UT}	20.0
G_M	25.0
N_U	25.0
A_{IF}	25.0
A_{UF}	40.0
M_L	40.0

TABLE 2

π_Q, Quality Factor for IMPATT Diodes

Quality Level	π_Q
JAN TXV	0.5
JAN TX	1.0
JAN	5.0
Lower	25.0

TABLE 3

Diodes Group VIII IMPATT Diodes

Base Failure Rate, λ_b, in Failures per 10^6 Hours

T(°C)	S									
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
0	0.182	0.227	0.273	0.318	0.386	0.455	0.534	0.636	0.795	1.060
10	0.204	0.250	0.306	0.364	0.420	0.500	0.602	0.739	0.955	1.250
20	0.239	0.284	0.341	0.398	0.477	0.568	0.693	0.875	1.136	1.700
25	0.250	0.307	0.364	0.420	0.500	0.602	0.739	0.955	1.250	2.045
30	0.273	0.318	0.386	0.454	0.534	0.636	0.795	1.057	1.477	
40	0.307	0.364	0.420	0.500	0.602	0.739	0.955	1.250	2.045	
50	0.341	0.398	0.477	0.568	0.693	0.875	1.136	1.704		
55	0.364	0.420	0.500	0.602	0.739	0.955	1.250	2.045		
60	0.386	0.454	0.534	0.636	0.795	1.057	1.477			
65	0.398	0.477	0.568	0.693	0.875	1.136	1.704			
70	0.420	0.500	0.602	0.739	0.955	1.250	2.045			
75	0.455	0.534	0.636	0.795	1.057	1.477				
80	0.477	0.568	0.693	0.875	1.136	1.704				
85	0.500	0.602	0.739	0.955	1.250	2.045				
90	0.534	0.636	0.795	1.057	1.477					
95	0.568	0.693	0.875	1.136	1.704					
100	0.602	0.738	0.955	1.250	2.045					
105	0.636	0.795	1.057	1.477						
110	0.693	0.875	1.136	1.704						
115	0.739	0.955	1.250	2.045						
120	0.795	1.057	1.477							
125	0.875	1.136	1.704							
130	0.955	1.250	2.045							
135	1.057	1.477								
140	1.136	1.704								
145	1.250	2.045								
150	1.470									
155	1.704									
160	2.045									

Diodes, Group VIII

Specification	**Description**
MIL-S-19500	PIN Diode

Part failure rate model (λ_P):

$$\lambda_P = \lambda_b (\pi_E \times \pi_Q \times \pi_P) \text{ failures}/10^6 \text{ hours.}$$

where the factors are shown in Tables 1 through 4.

TABLE 1

π_E for PIN Diodes

Environment	π_E
G_B	1.0
S_F	1.0
G_F	5.0
N_S	10.0
A_{IT}	12.0
A_{UT}	20.0
G_M	25.0
N_U	25.0
A_{IF}	25.0
A_{UF}	40.0
M_L	40.0

TABLE 2

Quality Factor, π_Q
For PIN Diode

Quality Level	π_Q
JAN TXV	0.5
JAN TX	1.0
JAN	5.0
Lower	25.0

TABLE 3

Power Rating Factor, π_P
for PIN Diodes

Power Rating	π_Q
<10W	1.0
10 - <100W	2.0
100W - <1kW	3.0
>1kW	4.0

TABLE 4

MIL-S-19500 Diodes, Group VII PIN Diodes

Base Failure Rate, λ_b, in Failures per Million Hours

T(°C)	S									
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
0	0.008	0.01	0.012	0.014	0.017	0.020	0.023	0.028	0.035	0.047
10	0.009	0.011	0.014	0.016	0.018	0.022	0.027	0.032	0.042	0.055
20	0.010	0.013	0.015	0.018	0.021	0.025	0.031	0.038	0.050	0.075
25	0.011	0.014	0.016	0.019	0.022	0.027	0.033	0.042	0.055	0.090
30	0.012	0.015	0.017	0.020	0.024	0.028	0.035	0.047	0.065	
40	0.014	0.016	0.018	0.022	0.027	0.033	0.042	0.055	0.090	
50	0.015	0.018	0.021	0.025	0.030	0.034	0.050	0.075		
55	0.016	0.019	0.022	0.027	0.033	0.042	0.055	0.090		
60	0.017	0.020	0.024	0.028	0.035	0.047	0.065			
65	0.018	0.021	0.025	0.030	0.038	0.050	0.075			
70	0.019	0.022	0.027	0.033	0.042	0.055	0.090			
75	0.020	0.024	0.028	0.035	0.047	0.065				
80	0.021	0.025	0.031	0.038	0.050	0.075				
85	0.022	0.027	0.033	0.042	0.055	0.090				
90	0.023	0.028	0.035	0.047	0.065					
95	0.025	0.030	0.038	0.050	0.075					
100	0.026	0.033	0.042	0.055	0.0900					
105	0.028	0.035	0.047	0.065						
110	0.031	0.037	0.050	0.075						
115	0.033	0.042	0.055	0.090						
120	0.035	0.047	0.065							
125	0.038	0.050	0.075							
130	0.042	0.055	0.090							
135	0.047	0.065								
140	0.050	0.075								
145	0.055	0.090								
150	0.065									
155	0.075									
160	0.090									

Section
DISCRETE SEMICONDUCTORS GaAs FET

Transistor, Group II
GaAs FET

Part Failure Rate Model (λ_P):

$$\lambda_P = \lambda_b \ (\pi_E \times \pi_Q \times \pi_P) \text{ failures}/10^6 \text{ hours}$$

Where the factors are shown in Tables 1 through 3.

TABLE 1

π_E for GaAs FETs

Environment	π_E
G_B	1.0
S_F	1.0
G_F	5.0
N_S	10.0
A_{IT}	12.0
A_{UT}	20.0
G_M	25.0
N_U	25.0
A_{IF}	25.0
A_{UF}	40.0
M_L	40.0

TABLE 2

π_Q, Quality Factor for GaAs FETs

Quality Level	π_Q
JANTXV	0.12
JANTX	0.24
JAN	1.2
Lower	6.0

TABLE 3

π_P Power Rating for Ga A_S FETs

Power Level	π_P
Low Noise Device	1.0
Driver	10.0

TABLE 4

GaAs FET
Base Failure Rate, λ_b, in Failures per 10^6 Hours

T (°C)	S 0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
0	0.064	0.076	0.090	0.111	0.131	0.152	0.170	0.214	0.269	0.360
10	0.070	0.083	0.104	0.124	0.145	0.166	0.200	0.249	0.325	0.456
20	0.083	0.097	0.114	0.138	0.159	0.193	0.235	0.297	0.401	0.608
25	0.085	0.104	0.125	0.145	0.166	0.201	0.249	0.325	0.456	0.692
30	0.090	0.111	0.131	0.152	0.180	0.214	0.270	0.360	0.526	
40	0.103	0.124	0.145	0.166	0.201	0.249	0.325	0.456	0.692	
50	0.117	0.138	0.159	0.194	0.235	0.297	0.401	0.608		
55	0.124	0.145	0.166	0.200	0.249	0.325	0.456	0.692		
60	0.131	0.152	0.180	0.214	0.270	0.360	0.525			
65	0.138	0.160	0.194	0.235	0.297	0.401	0.608			
70	0.145	0.166	0.200	0.249	0.325	0.456	0.692			
75	0.152	0.180	0.214	0.270	0.360	0.525				
80	0.159	0.194	0.235	0.297	0.401	0.608				
85	0.166	0.200	0.249	0.325	0.456	0.692				
90	0.180	0.214	0.270	0.360	0.525					
95	0.194	0.235	0.297	0.401	0.608					
100	0.200	0.249	0.325	0.456	0.692					
105	0.214	0.270	0.360	0.525						
110	0.235	0.297	0.401	0.608						
115	0.249	0.325	0.456	0.692						
120	0.270	0.360	0.525							
125	0.297	0.401	0.608							
130	0.325	0.456	0.692							
135	0.359	0.525								
140	0.401	0.608								
145	0.456	0.692								
150	0.525									
155	0.608									
160	0.692									

Section
FERRITE ISOLATORS AND CIRCULATORS (WAVEGUARD)

Part Failure Rate Model (λ_p)

$$\lambda_p = \lambda_b \ (\pi_E \times \pi_P) \text{ failures}/10^6 \text{ hours}$$

Where λ_b = base failure rate (.2 failures/10^6 hours)

π_E = Environmental Factor (See Table 1)

π_P = Power Rating Factor (See Table 2)

TABLE 1

Environmental Factor π_E for Isolators and Circulators

Environment	Π_E
G_B	1.0
S_F	1.0
G_F	2.0
N_S	5.0
A_{IT}	5.0
A_{UT}	6.0
G_M	6.0
N_U	7.0
A_{IF}	7.0
A_{UF}	10.0
M_L	10.0

TABLE 2

Power Rating Factor π_P for Isolators and Circulators

Power Rating	π_P
$\leq$100W	1.0
>100W	2.0

Section
MICROWAVE CAPACITORS

Part Failure Rate Model (λ_b)

$$\lambda_P = \lambda_b \times \pi_E \text{ failures}/10^6 \text{ hours}$$

Where

λ_b = Base failure rate (0.6 failures/10^6 hours)

π_E = Environmental Factor (see Table 1)

TABLE 1

π_E Environmental Factors for
Microwave Capacitors

Environment	π_E
G_B	1.0
S_F	1.0
G_F	2.0
N_S	2.5
G_M	6.0
A_{IT}	6.0
A_{IF}	12.0
N_U	18.0
A_{UT}	24.0
A_{UF}	48.0
M_L	30.0

Section
DISCRETE SEMICONDUCTORS LOW NOISE TRANSISTORS

Transistor, Group I

SPECIFICATION

MIL-S-19500

Part Failure Rate Model (λ_P)

$$\lambda_P = \lambda_b\ (\pi_E \times \pi_Q \times \pi_R \times \pi_{S2})\ \text{failures}/10^6\ \text{hours}$$

Where
λ_b = Base Failure Rate (See Table 5)
π_E = Environmental Factor (See Table 1)
π_Q = Quality Factor (See Table 2)
π_R = Power Rating Factor (See Table 4)
π_{S2} = Voltage Stress Factor (See Table 3)

TABLE 1

π_E for Low Noise Transistors

Environment	π_E
G_B	1.0
S_F	1.0
G_F	5.0
N_S	10.0
A_{IT}	12.0
A_{UT}	20.0
G_M	25.0
N_U	25.0
A_{IF}	25.0
A_{UF}	40.0
M_L	40.0

TABLE 2

π_Q, Quality Factor for Low Noise Transistors

Quality Level	π_Q
JANTXV	0.12
JANTX	0.24
JAN	1.2
Lower	6.0

TABLE 3

Voltage Stress Factor π_{S2} for Low Noise Transistors

S_2	π_{S2}
100	3.00
90	2.25
80	1.65
70	1.20
60	0.88
50	0.64
40	0.48
30	0.36
20	0.30
10	0.30
0	0.30

TABLE 4

π_R Power Rating Factor for Low Noise Transistors

Power Rating (Watts)	π_R
≤ 1	1.0
>1	1.5

TABLE 5

MIL-S-19500 Low Noise Transistors

Base Failure Rate, λ_b, in Failures per 10^6 Hours

T (°C)	S									
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
0	0.052	0.063	0.074	0.088	0.103	0.122	0.146	0.169	0.216	0.277
10	0.058	0.071	0.083	0.099	0.115	0.137	0.154	0.202	0.262	0.354
20	0.066	0.078	0.092	0.109	0.129	0.154	0.185	0.231	0.308	0.447
25	0.071	0.083	0.099	0.116	0.137	0.162	0.202	0.262	0.354	0.508
30	0.073	0.088	0.103	0.122	0.146	0.169	0.216	0.277	0.385	
40	0.083	0.099	0.116	0.137	0.154	0.200	0.262	0.354	0.508	
50	0.092	0.109	0.129	0.154	0.185	0.231	0.308	0.447		
55	0.098	0.116	0.137	0.162	0.200	0.262	0.354	0.508		
60	0.103	0.122	0.146	0.169	0.216	0.277	0.385			
65	0.109	0.129	0.154	0.185	0.231	0.308	0.447			
70	0.116	0.137	0.162	0.200	0.262	0.354	0.508			
75	0.122	0.146	0.169	0.216	0.277	0.385				
80	0.129	0.154	0.185	0.231	0.308	0.447				
85	0.137	0.162	0.200	0.261	0.354	0.508				
90	0.146	0.169	0.216	0.277	0.385					
95	0.154	0.185	0.231	0.308	0.447					
100	0.162	0.200	0.262	0.354	0.508					
105	0.169	0.216	0.277	0.385						
110	0.185	0.231	0.308	0.447						
115	0.200	0.262	0.354	0.508						
120	0.216	0.277	0.385							
125	0.231	0.308	0.447							
130	0.262	0.354	0.508							
135	0.277	0.385								
140	0.308	0.447								
145	0.354	0.508								
150	0.385									
155	0.447									
160	0.508									

Section
FERRITE PHASE SHIFTER (LATCHING)

Part Failure Rate Model (λ_p))

$$\lambda_p = \lambda_b \times \pi_E \text{ (Failure/}10^6\text{ hours)}$$

Where λ_b = base failure rate (.15 failures/10^6 hours)

π_E = Environmental Factor (See Table 1)

TABLE 1

Environmental Factor π_E
for Ferrite Phase Shifter

Environment	π_E
S_F	1.0
G_B	1.0
G_F	2.0
N_S	5.0
A_{IT}	5.0
A_{UT}	6.0
G_M	6.0
N_U.	7.0
A_{IF}	7.0
A_{UF}	10.0
M_L	10.0

Section
DUMMY LOADS AND TERMINATIONS
MIL-D-3954C

Dummy Load (Refractory)

Specification	Description
MIL-D-3954C	Dummy Load

Part Failure Rate Model (λ_P)

$$\lambda_P = \lambda_b (\pi_E \times \pi_P) \text{ failures}/10^6 \text{ hours}$$

Where

λ_b = base failure rate (0.005 failures/10^6 hours)
π_E = Environmental Factor (See Table 1)
π_P = Power rating factor (See Table 2)

TABLE 1

Environmental Factor (π_E) for Dummy Loads and Terminations

Environmental	π_E
G_B	1.0
S_F	1.0
G_F	2.0
N_S	2.0
G_M	6.0
A_{IT}	6.0
A_{IF}	12.0
N_U	13.5
A_{UT}	15.0
A_{UF}	30.0
M_L	35.0

TABLE 2

Power Rating Factor π_P for Dummy Loads and Terminations

Power Rating	π_P
Dummy Load	
<100W	1
100W - 1kW	50
>1kW	100
Terminations	50

Section
SURFACE ACOUSTIC WAVE DEVICES

Part Failure Rate Model (λ_P)

$$\lambda_P = \lambda_b \times \pi_E \text{ failures}/10^6 \text{ hours}$$

Where λ_b = base failure rate (.2 failures/106 hours)

π_E = Environmental Factor (See Table 1)

TABLE 1

Environmental Factor π_E for
Surface Acoustic Wave Devices

Environment	π_E
S_F	1.0
G_B	1.0
G_F	2.0
G_M	3.0
A_{IT}	5.0
N_S	5.0
A_{IF}	6.0
A_{UT}	7.0
N_U	7.0
A_{UF}	8.0
M_L	10.0

Section
DISCRETE SEMICONDUCTORS, VARACTOR

Diodes, Group VII

SPECIFICATION	DESCRIPTION
MIL-S-19500	Varactor

Part Failure Rate Model (λ_P)

$$\lambda_P = \lambda_b \ (\pi_E \times \pi_2 \times \pi_A) \text{ failures}/10^6 \text{ hours}$$

Where the factors are shown in Tables 1 through 4.

TABLE 1

π_E for Varactor Diodes

Environment	π_E
G_B	1
S_F	1
G_F	5
N_S	10
A_{IT}	12
A_{UT}	20
G_M	25
N_U	25
A_{IF}	25
A_{UF}	40
M_L	40

TABLE 2

π_Q, Quality Factor for Varactor Diodes

Quality Level	π_Q
JAN TXV	0.5
JAN TX	1.0
JAN	5.0
Lower	25.0

TABLE 3

π_A Application Factor for Varactor Diodes

Application	π_A
Voltage Control	1.0
Multiplier	5.0

TABLE 4

MIL-S-19500 Diodes, Group VII Varactors

Base Failure Rate, λ_b, in Failures per 10^6 Hours

(T°C)	S									
	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
0	0.008	0.010	0.012	0.014	0.017	0.020	0.024	0.028	0.035	0.047
10	0.009	0.011	0.014	0.016	0.018	0.022	0.027	0.033	0.042	0.055
20	0.011	0.013	0.015	0.018	0.021	0.025	0.031	0.038	0.050	0.075
25	0.011	0.014	0.016	0.019	0.022	0.027	0.033	0.042	0.055	0.090
30	0.012	0.014	0.017	0.020	0.024	0.028	0.035	0.047	0.065	
40	0.014	0.016	0.018	0.022	0.027	0.033	0.042	0.055	0.090	
50	0.015	0.017	0.021	0.025	0.031	0.038	0.055	0.075		
55	0.016	0.018	0.022	0.027	0.033	0.042	0.055	0.090		
60	0.017	0.020	0.024	0.028	0.035	0.047	0.065			
65	0.018	0.021	0.025	0.031	0.038	0.050	0.075			
70	0.018	0.022	0.027	0.033	0.042	0.055	0.090			
75	0.020	0.023	0.028	0.035	0.047	0.065				
80	0.021	0.025	0.030	0.034	0.050	0.075				
70	0.018	0.022	0.027	0.033	0.042	0.055	0.090			
75	0.020	0.023	0.028	0.035	0.047	0.065				
80	0.021	0.025	0.030	0.038	0.050	0.075				
85	0.022	0.027	0.033	0.042	0.055	0.090				
90	0.024	0.028	0.035	0.047	0.065					
95	0.025	0.030	0.038	0.050	0.075					
100	0.027	0.033	0.042	0.055	0.090					
105	0.028	0.035	0.047	0.065						
110	0.030	0.038	0.050	0.075						
115	0.033	0.042	0.055	0.090						
120	0.035	0.047	0.065							
125	0.038	0.050	0.075							
130	0.042	0.055	0.090							
135	0.047	0.065								
140	0.050	0.075								
145	0.055	0.090								
150	0.065									
155	0.075									

Section
YIG FILTERS

Part Failure Rate Model (λ_P)

$$\lambda_P = \lambda_b \times \pi_E \text{ failures}/10^6 \text{ hours}$$

Where λ_b = base failure rate (0.2 failures/10^6 hours)

π_E = Environmental Factor (See Table 1)

TABLE 1

Environmental Factor π_E
for YIG Filters

Environment	π_E
S_F	1.0
G_B	1.0
G_F	2.0
G_M	3.0
A_{IT}	5.0
N_S	5.0
A_{IF}	6.0
A_{UT}	7.0
N_U	7.0
A_{UF}	8.0
M_L	10.0

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